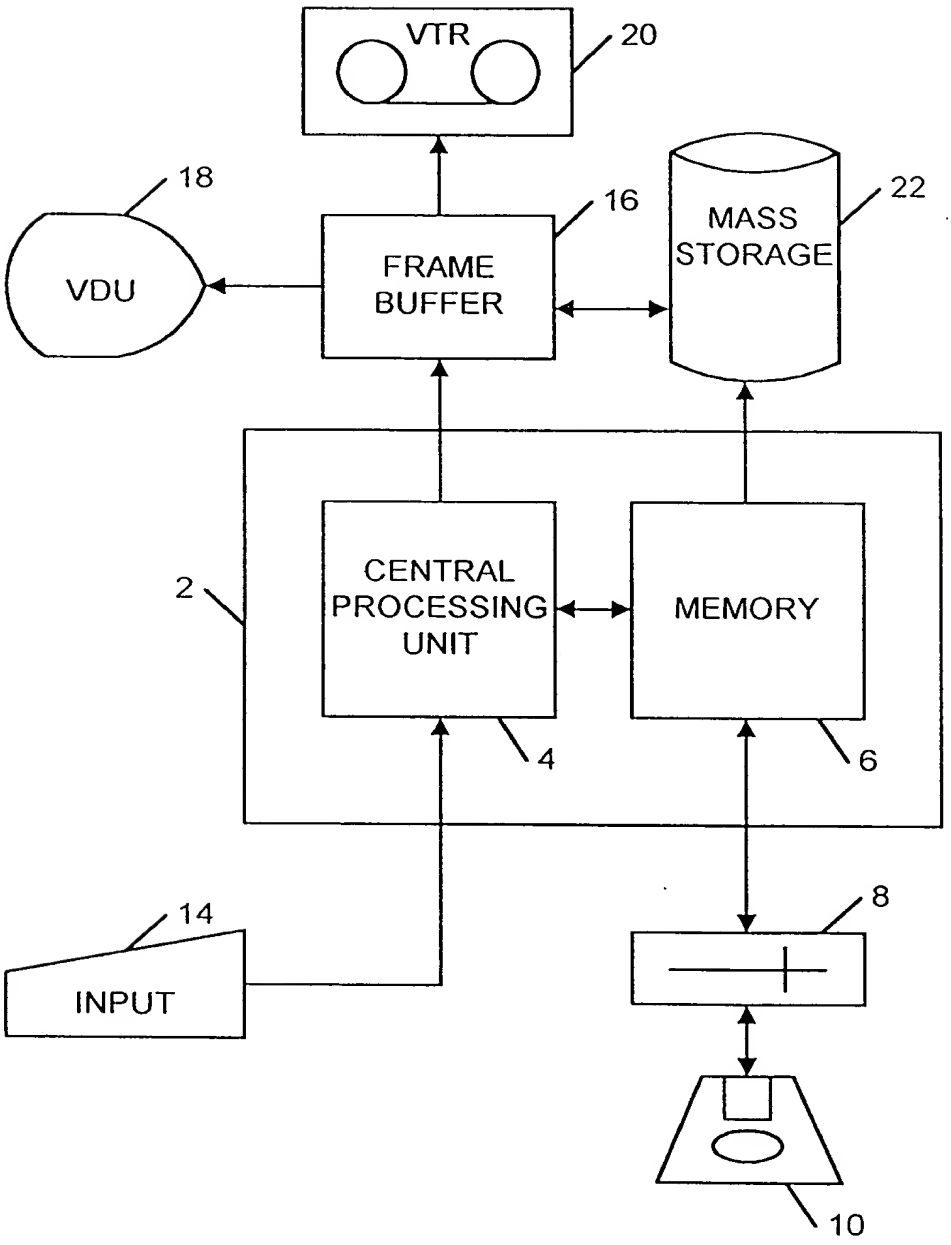

VTR
20
18
16
22
VDU
FRAME BUFFER
MASS STORAGE
2
CENTRAL PROCESSING UNIT
MEMORY
4
6
14
8
INPUT
10

FIG. 1

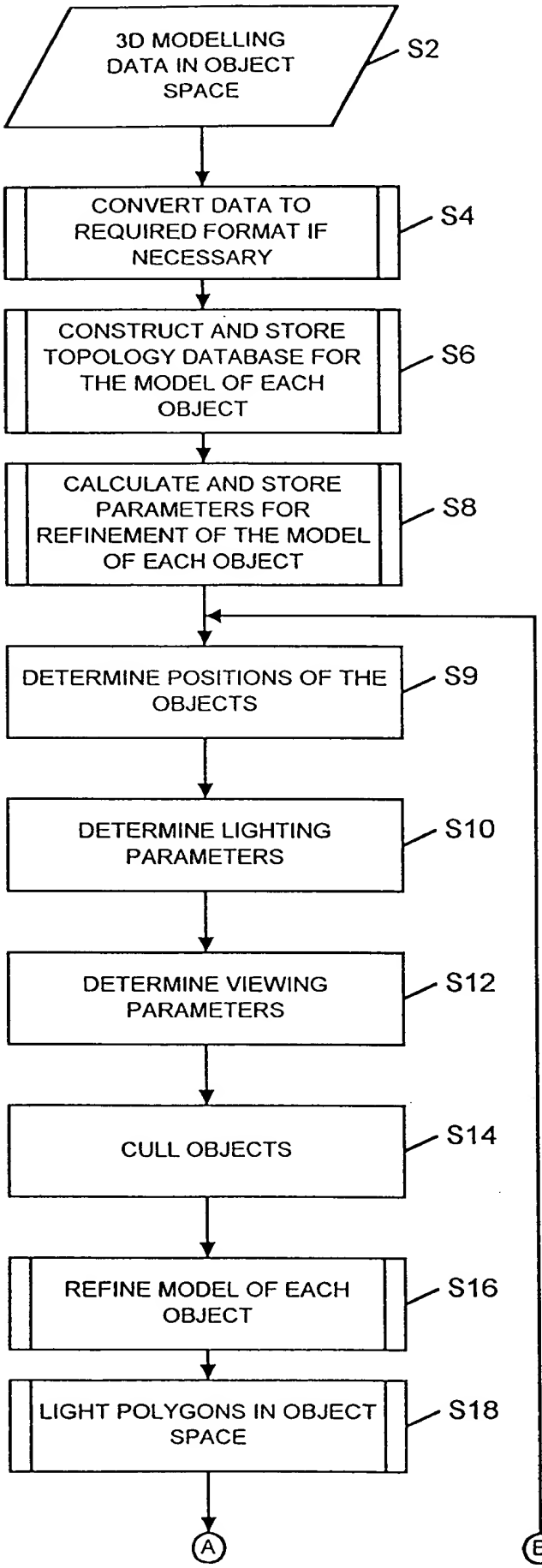

3D MODELLING DATA IN OBJECT SPACE
S2
CONVERT DATA TO REQUIRED FORMAT IF NECESSARY
S4
CONSTRUCT AND STORE TOPOLOGY DATABASE FOR THE MODEL OF EACH OBJECT
S6
CALCULATE AND STORE PARAMETERS FOR REFINEMENT OF THE MODEL OF EACH OBJECT
S8
DETERMINE POSITIONS OF THE OBJECTS
S9
DETERMINE LIGHTING PARAMETERS
S10
DETERMINE VIEWING PARAMETERS
S12
CULL OBJECTS
S14
REFINE MODEL OF EACH OBJECT
S16
LIGHT POLYGONS IN OBJECT SPACE
S18
A
B

FIG. 2

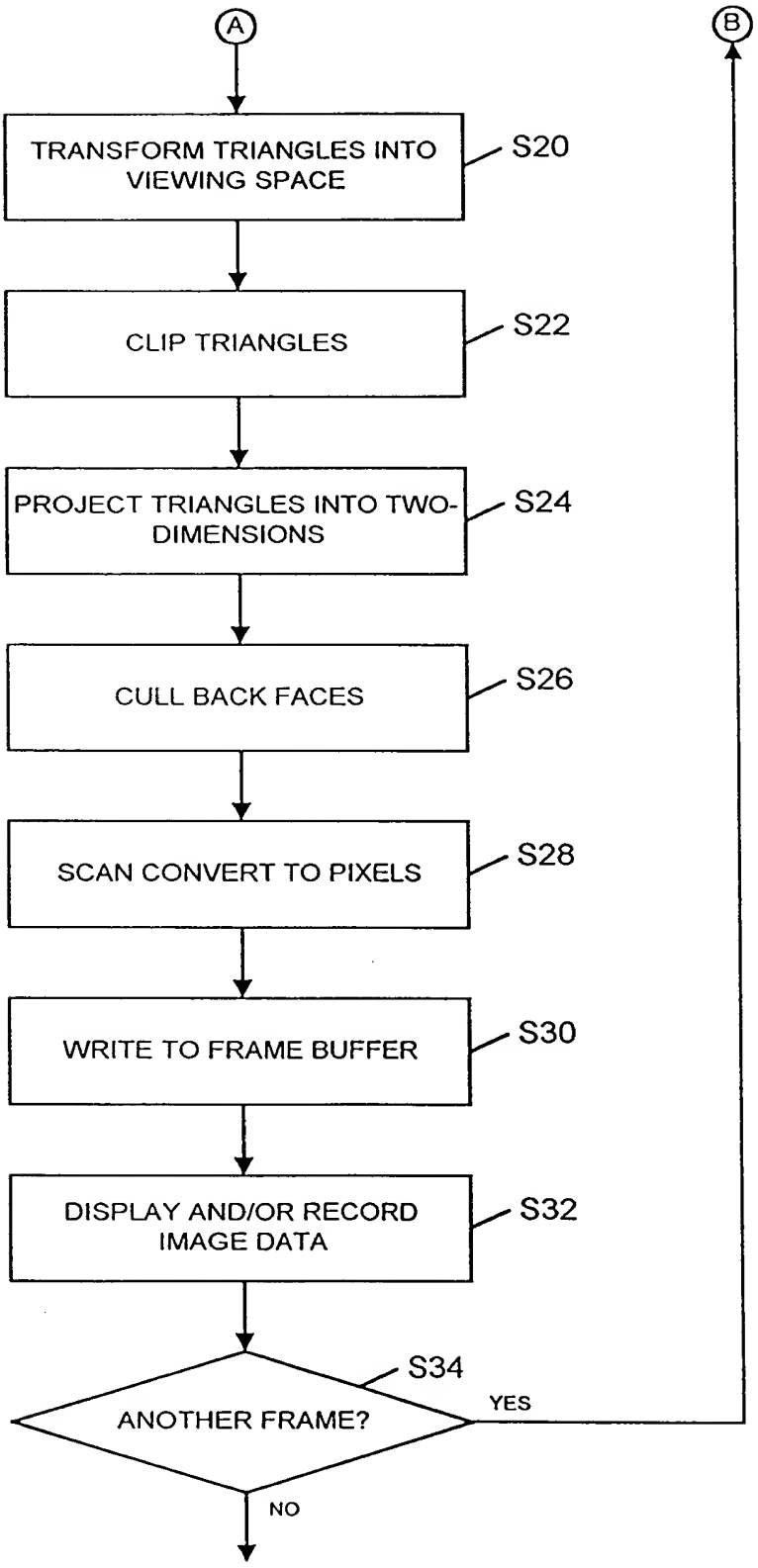

A
B
TRANSFORM TRIANGLES INTO VIEWING SPACE
S20
CLIP TRIANGLES
S22
PROJECT TRIANGLES INTO TWO-DIMENSIONS
S24
CULL BACK FACES
S26
SCAN CONVERT TO PIXELS
S28
WRITE TO FRAME BUFFER
S30
DISPLAY AND/OR RECORD IMAGE DATA
S32
S34
ANOTHER FRAME?
YES
NO

FIG. 2 (cont)

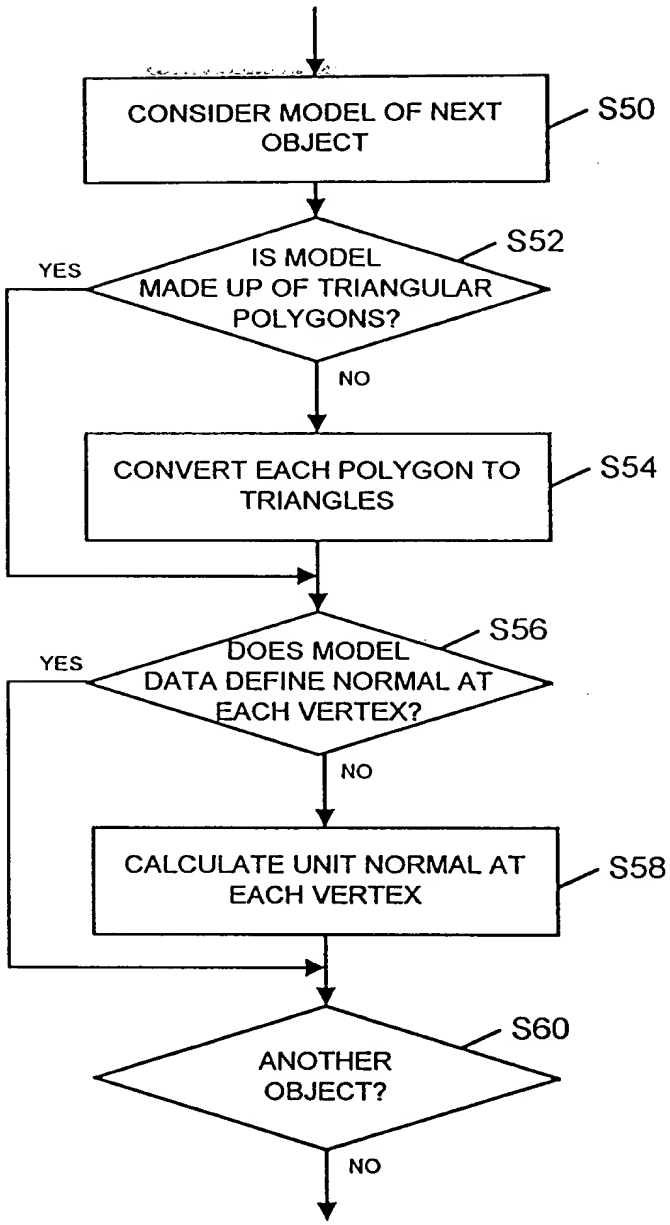

CONSIDER MODEL OF NEXT OBJECT
S50
IS MODEL MADE UP OF TRIANGULAR POLYGONS?
S52
YES
NO
CONVERT EACH POLYGON TO TRIANGLES
S54
DOES MODEL DATA DEFINE NORMAL AT EACH VERTEX?
S56
YES
NO
CALCULATE UNIT NORMAL AT EACH VERTEX
S58
ANOTHER OBJECT?
S60
NO

FIG. 3

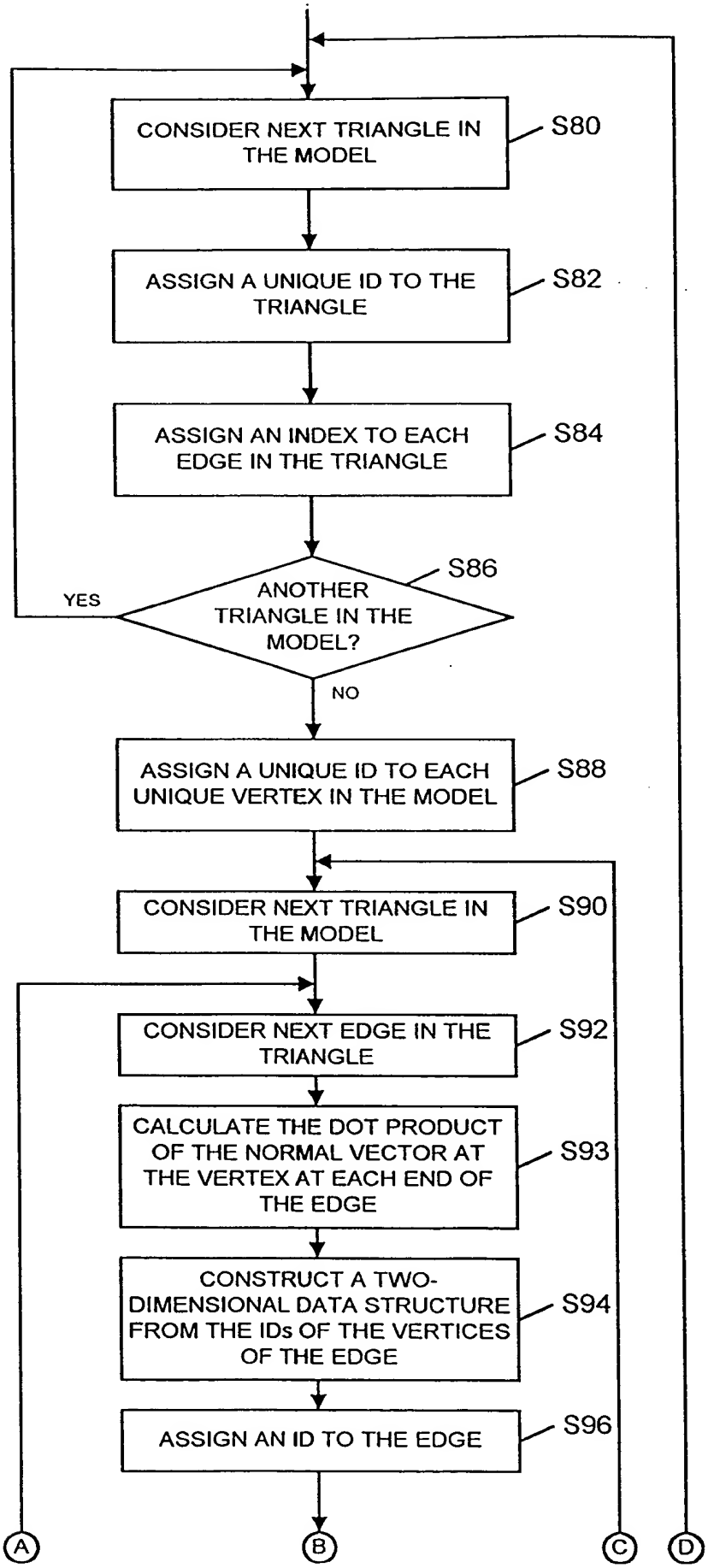

CONSIDER NEXT TRIANGLE IN THE MODEL
S80
ASSIGN A UNIQUE ID TO THE TRIANGLE
S82
ASSIGN AN INDEX TO EACH EDGE IN THE TRIANGLE
S84
ANOTHER TRIANGLE IN THE MODEL?
S86
YES
NO
ASSIGN A UNIQUE ID TO EACH UNIQUE VERTEX IN THE MODEL
S88
CONSIDER NEXT TRIANGLE IN THE MODEL
S90
CONSIDER NEXT EDGE IN THE TRIANGLE
S92
CALCULATE THE DOT PRODUCT OF THE NORMAL VECTOR AT THE VERTEX AT EACH END OF THE EDGE
S93
CONSTRUCT A TWO-DIMENSIONAL DATA STRUCTURE FROM THE IDs OF THE VERTICES OF THE EDGE
S94
ASSIGN AN ID TO THE EDGE
S96
A
B
C
D

FIG. 4

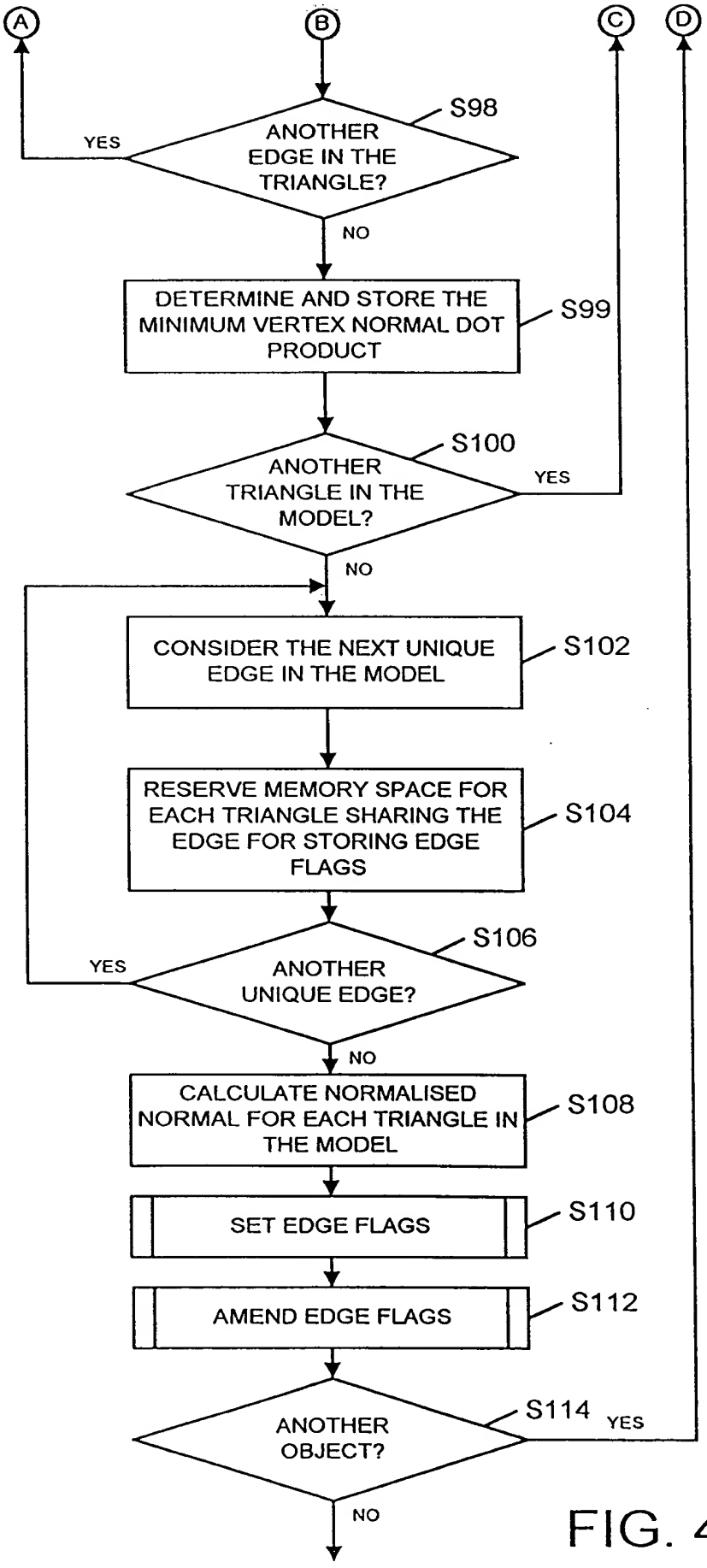

A
B
C
D
S98
ANOTHER EDGE IN THE TRIANGLE?
YES
NO
DETERMINE AND STORE THE MINIMUM VERTEX NORMAL DOT PRODUCT
S99
S100
ANOTHER TRIANGLE IN THE MODEL?
YES
NO
CONSIDER THE NEXT UNIQUE EDGE IN THE MODEL
S102
RESERVE MEMORY SPACE FOR EACH TRIANGLE SHARING THE EDGE FOR STORING EDGE FLAGS
S104
S106
ANOTHER UNIQUE EDGE?
YES
NO
CALCULATE NORMALISED NORMAL FOR EACH TRIANGLE IN THE MODEL
S108
SET EDGE FLAGS
S110
AMEND EDGE FLAGS
S112
S114
ANOTHER OBJECT?
YES
NO

FIG. 4 (cont)

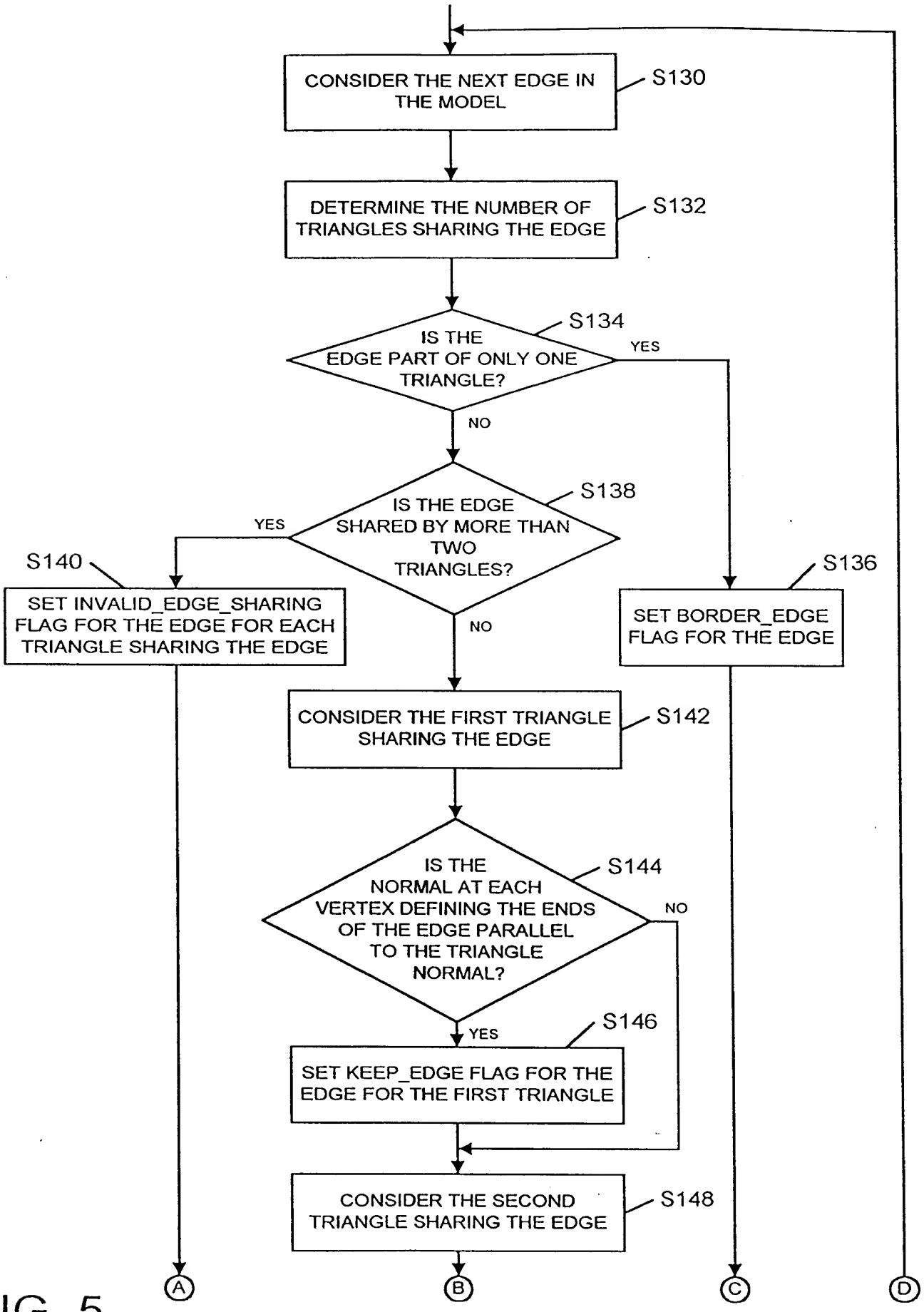

CONSIDER THE NEXT EDGE IN THE MODEL
S130
DETERMINE THE NUMBER OF TRIANGLES SHARING THE EDGE
S132
IS THE EDGE PART OF ONLY ONE TRIANGLE?
S134
YES
NO
IS THE EDGE SHARED BY MORE THAN TWO TRIANGLES?
S138
YES
NO
SET INVALID_EDGE_SHARING FLAG FOR THE EDGE FOR EACH TRIANGLE SHARING THE EDGE
S140
SET BORDER_EDGE FLAG FOR THE EDGE
S136
CONSIDER THE FIRST TRIANGLE SHARING THE EDGE
S142
IS THE NORMAL AT EACH VERTEX DEFINING THE ENDS OF THE EDGE PARALLEL TO THE TRIANGLE NORMAL?
S144
NO
YES
SET KEEP_EDGE FLAG FOR THE EDGE FOR THE FIRST TRIANGLE
S146
CONSIDER THE SECOND TRIANGLE SHARING THE EDGE
S148
A
B
C
D

FIG. 5

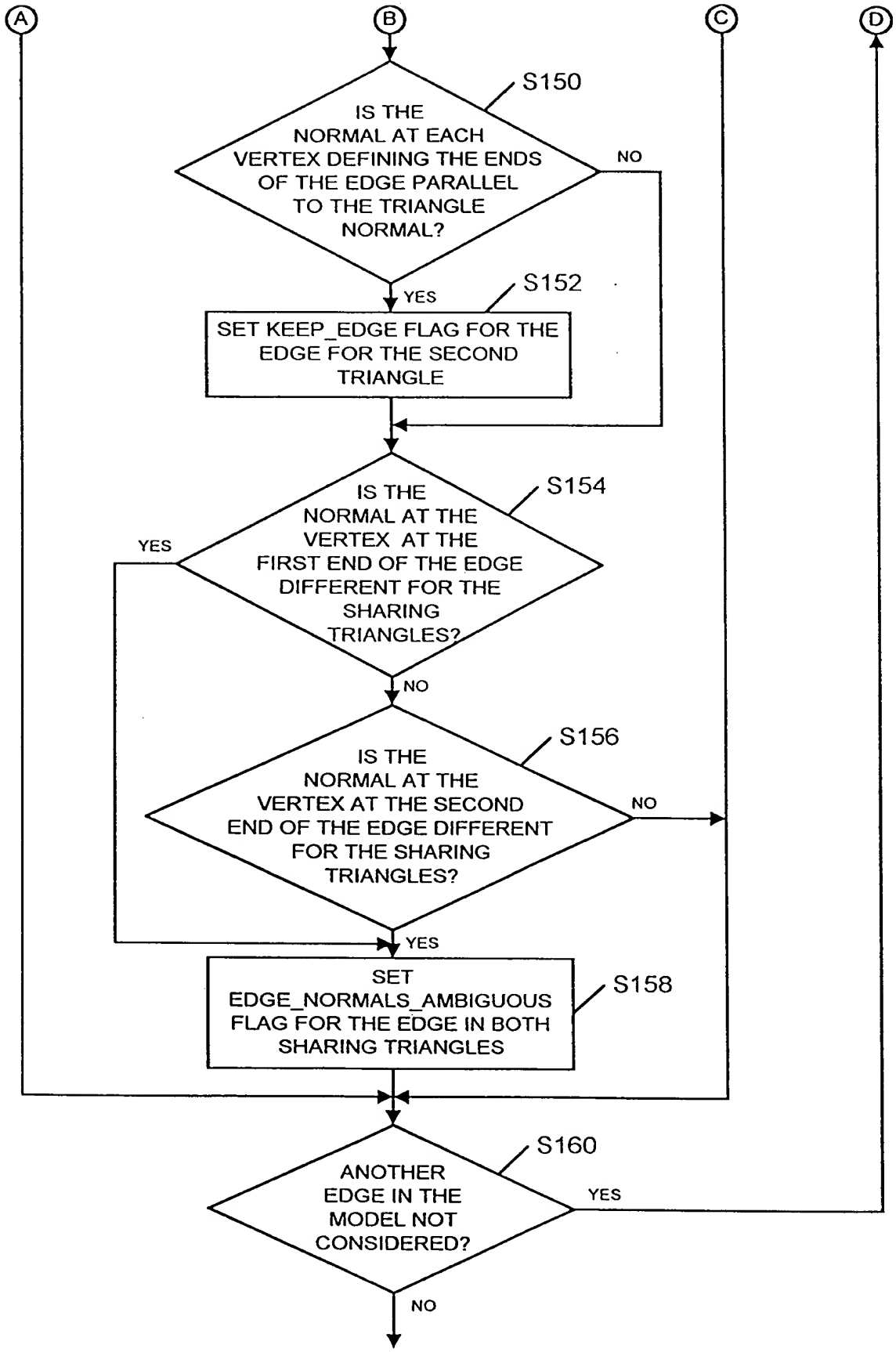

A
B
C
D
S150
IS THE NORMAL AT EACH VERTEX DEFINING THE ENDS OF THE EDGE PARALLEL TO THE TRIANGLE NORMAL?
NO
YES
S152
SET KEEP_EDGE FLAG FOR THE EDGE FOR THE SECOND TRIANGLE
S154
IS THE NORMAL AT THE VERTEX AT THE FIRST END OF THE EDGE DIFFERENT FOR THE SHARING TRIANGLES?
YES
NO
S156
IS THE NORMAL AT THE VERTEX AT THE SECOND END OF THE EDGE DIFFERENT FOR THE SHARING TRIANGLES?
NO
YES
SET EDGE_NORMALS_AMBIGUOUS FLAG FOR THE EDGE IN BOTH SHARING TRIANGLES
S158
S160
ANOTHER EDGE IN THE MODEL NOT CONSIDERED?
YES
NO

FIG. 5 (cont)

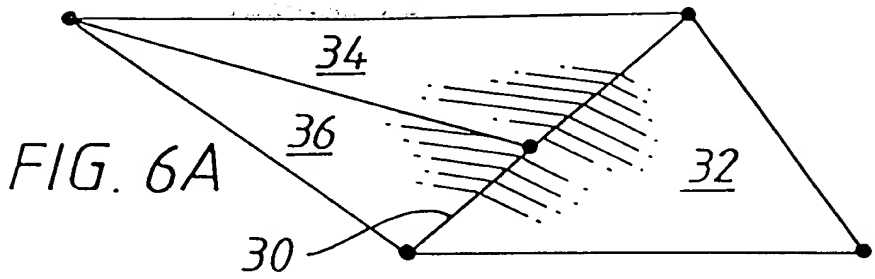


FIG. 6A

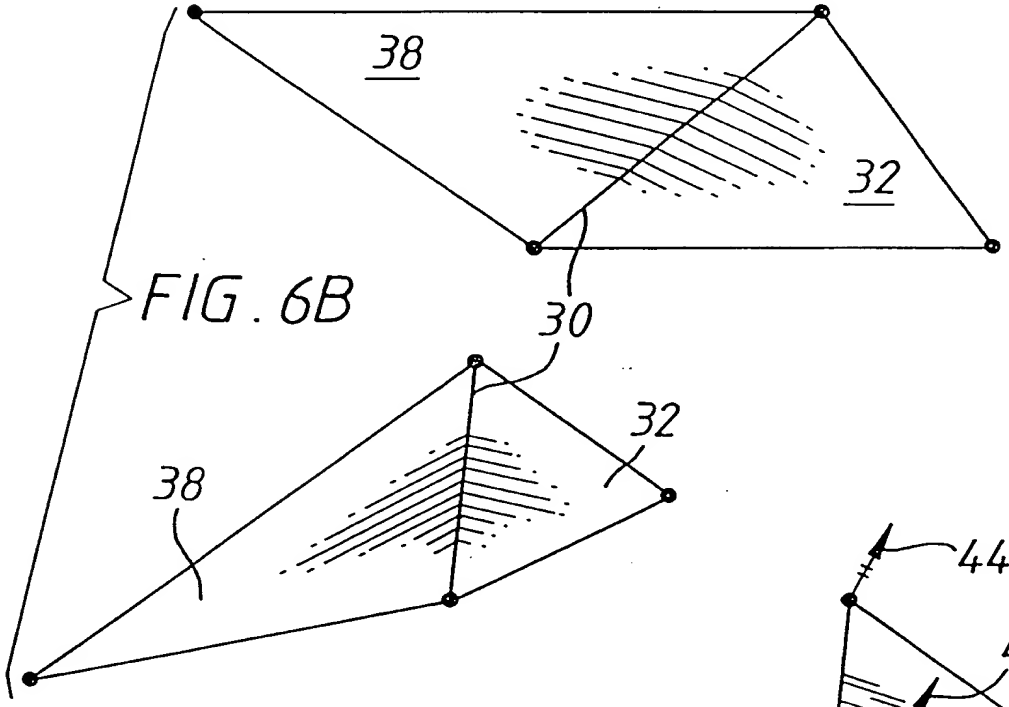


FIG. 6B

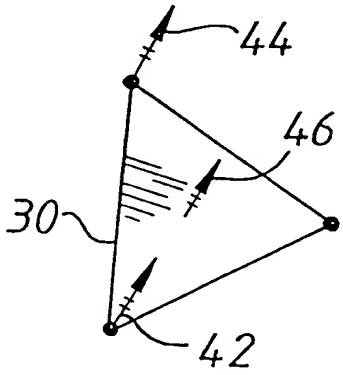


FIG. 6C

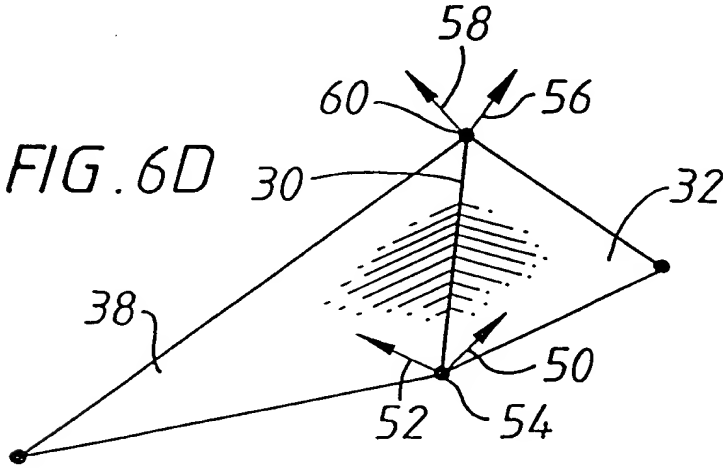


FIG. 6D

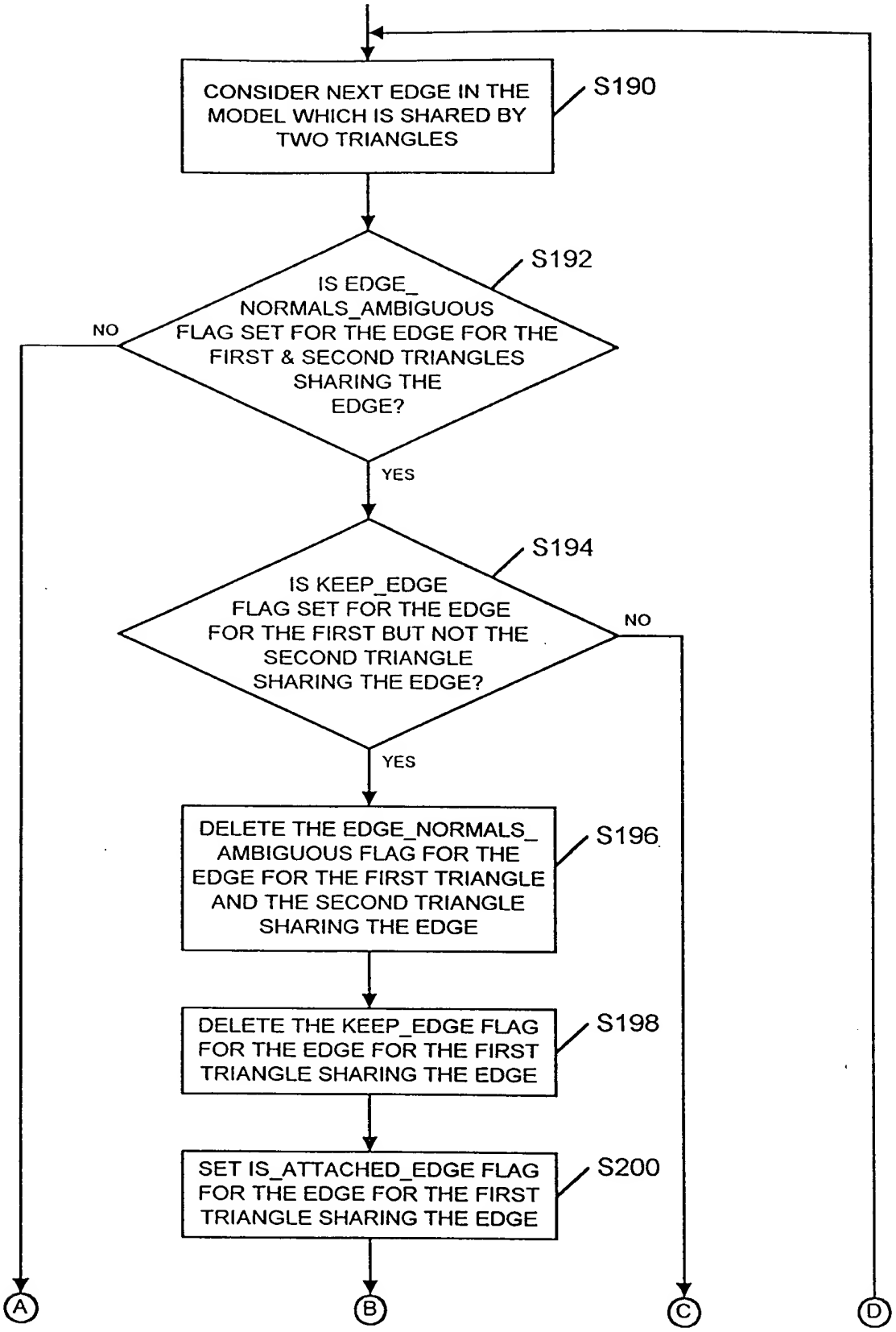

CONSIDER NEXT EDGE IN THE MODEL WHICH IS SHARED BY TWO TRIANGLES
S190
IS EDGE_ NORMALS_AMBIGUOUS FLAG SET FOR THE EDGE FOR THE FIRST & SECOND TRIANGLES SHARING THE EDGE?
S192
NO
YES
IS KEEP_EDGE FLAG SET FOR THE EDGE FOR THE FIRST BUT NOT THE SECOND TRIANGLE SHARING THE EDGE?
S194
NO
YES
DELETE THE EDGE_NORMALS_ AMBIGUOUS FLAG FOR THE EDGE FOR THE FIRST TRIANGLE AND THE SECOND TRIANGLE SHARING THE EDGE
S196
DELETE THE KEEP_EDGE FLAG FOR THE EDGE FOR THE FIRST TRIANGLE SHARING THE EDGE
S198
SET IS_ATTACHED_EDGE FLAG FOR THE EDGE FOR THE FIRST TRIANGLE SHARING THE EDGE
S200
A
B
C
D

FIG. 7

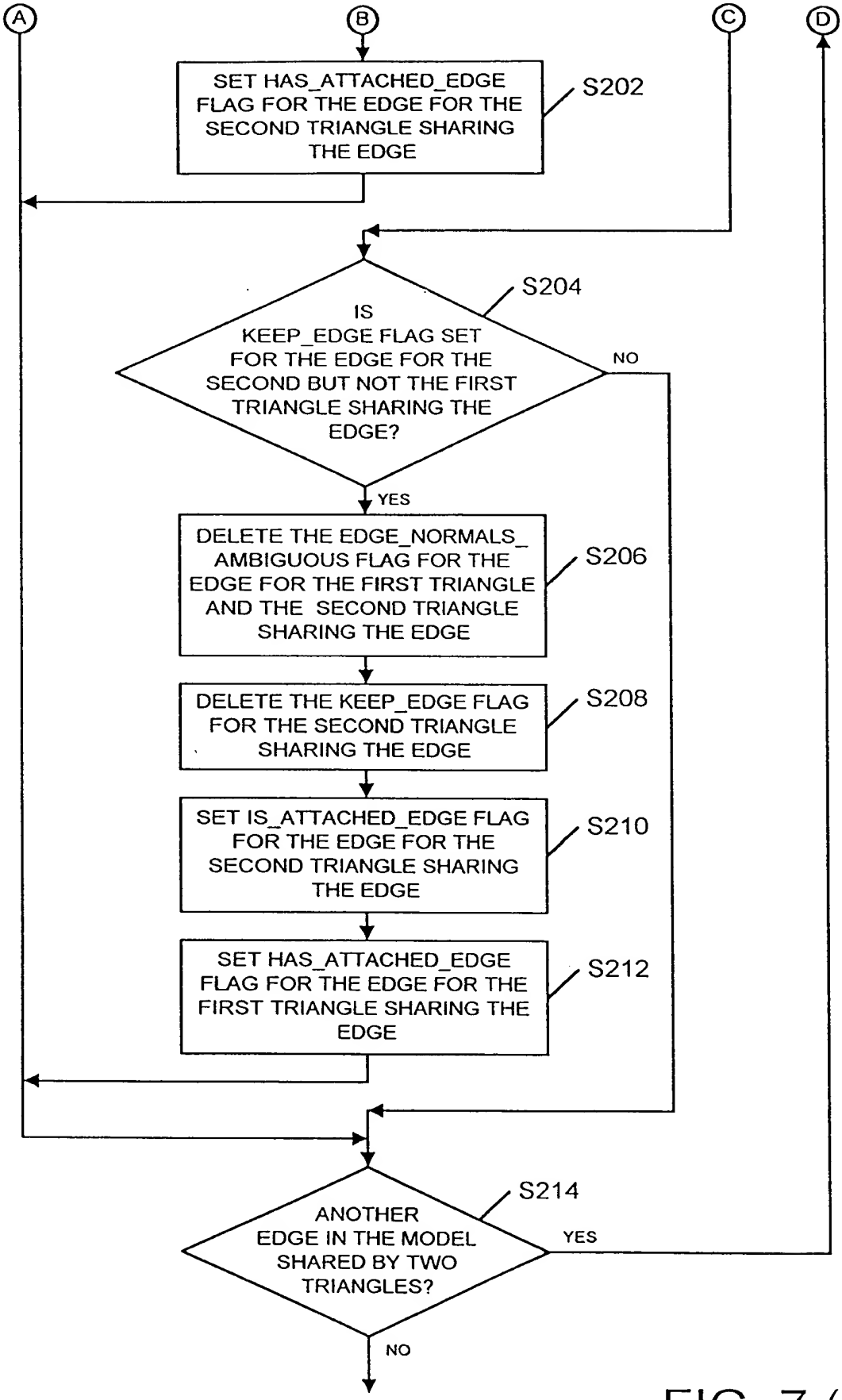

A
B
C
D
SET HAS_ATTACHED_EDGE FLAG FOR THE EDGE FOR THE SECOND TRIANGLE SHARING THE EDGE
S202
IS KEEP_EDGE FLAG SET FOR THE EDGE FOR THE SECOND BUT NOT THE FIRST TRIANGLE SHARING THE EDGE?
S204
NO
YES
DELETE THE EDGE_NORMALS_AMBIGUOUS FLAG FOR THE EDGE FOR THE FIRST TRIANGLE AND THE SECOND TRIANGLE SHARING THE EDGE
S206
DELETE THE KEEP_EDGE FLAG FOR THE SECOND TRIANGLE SHARING THE EDGE
S208
SET IS_ATTACHED_EDGE FLAG FOR THE EDGE FOR THE SECOND TRIANGLE SHARING THE EDGE
S210
SET HAS_ATTACHED_EDGE FLAG FOR THE EDGE FOR THE FIRST TRIANGLE SHARING THE EDGE
S212
ANOTHER EDGE IN THE MODEL SHARED BY TWO TRIANGLES?
S214
YES
NO

FIG. 7 (cont)

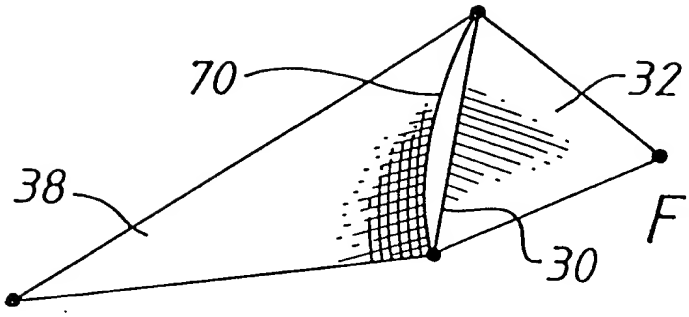


FIG. 8A

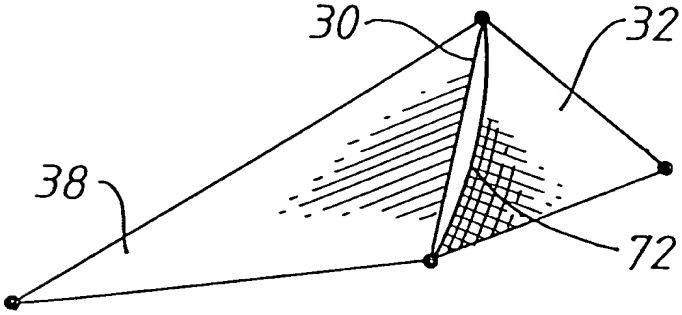


FIG. 8B

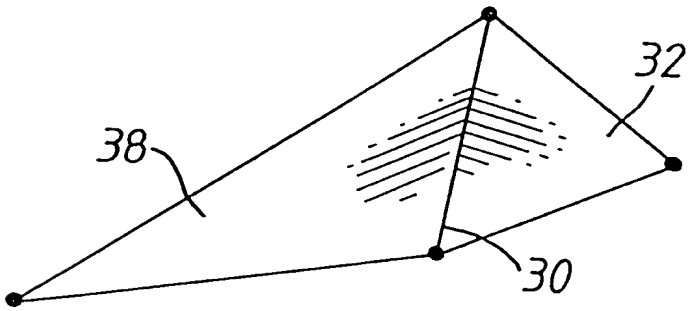


FIG. 8C

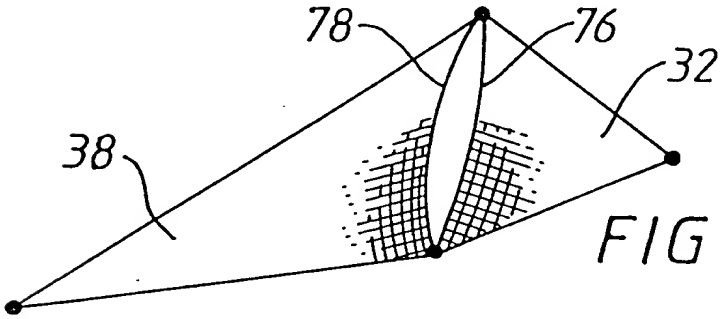


FIG. 8D

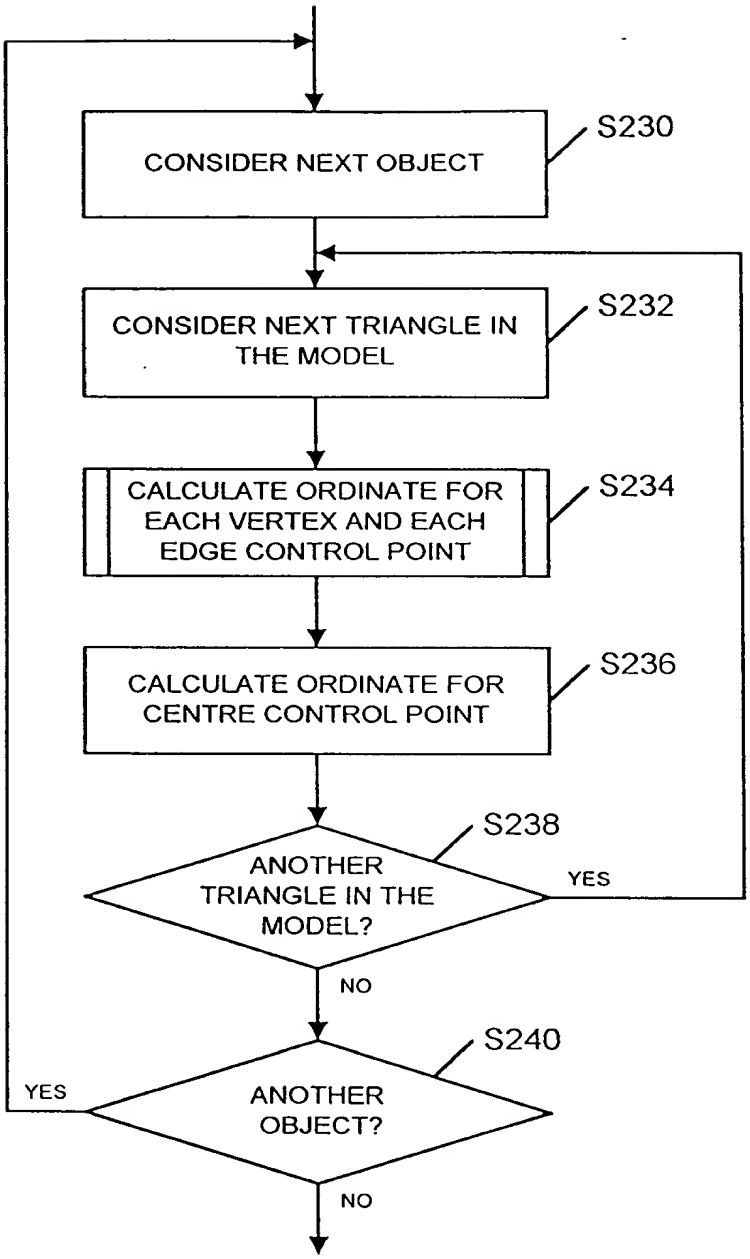
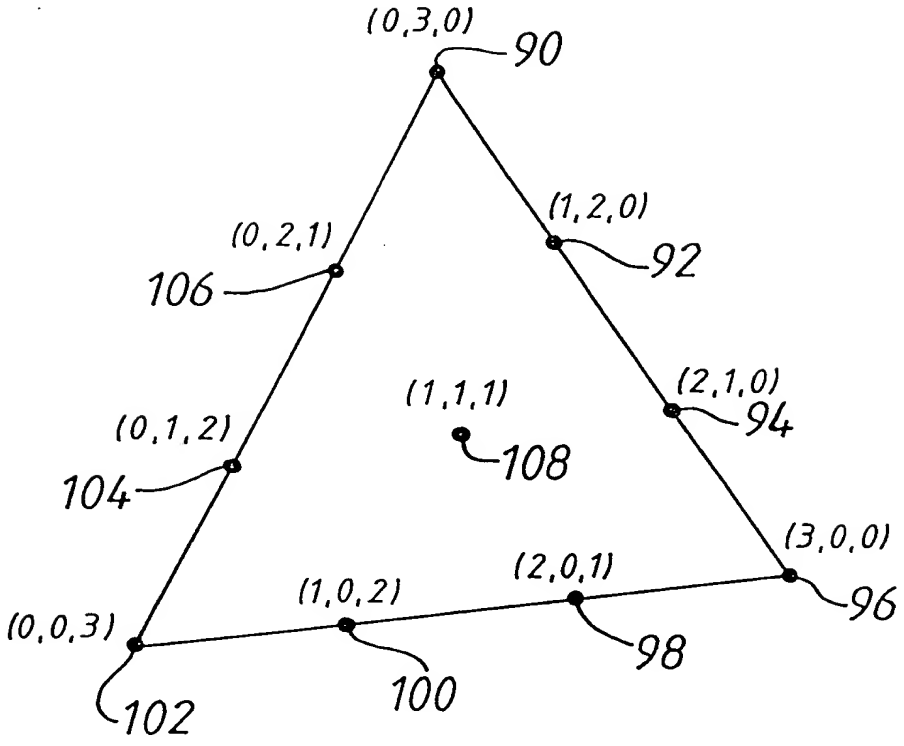

CONSIDER NEXT OBJECT
S230
CONSIDER NEXT TRIANGLE IN THE MODEL
S232
CALCULATE ORDINATE FOR EACH VERTEX AND EACH EDGE CONTROL POINT
S234
CALCULATE ORDINATE FOR CENTRE CONTROL POINT
S236
ANOTHER TRIANGLE IN THE MODEL?
S238
YES
NO
ANOTHER OBJECT?
S240
YES
NO

FIG. 9

FIG. 10


(0,3,0)
90
(1,2,0)
92
(0,2,1)
106
(2,1,0)
94
(1,1,1)
108
(0,1,2)
104
(3,0,0)
96
(2,0,1)
(1,0,2)
98
(0,0,3)
100
102

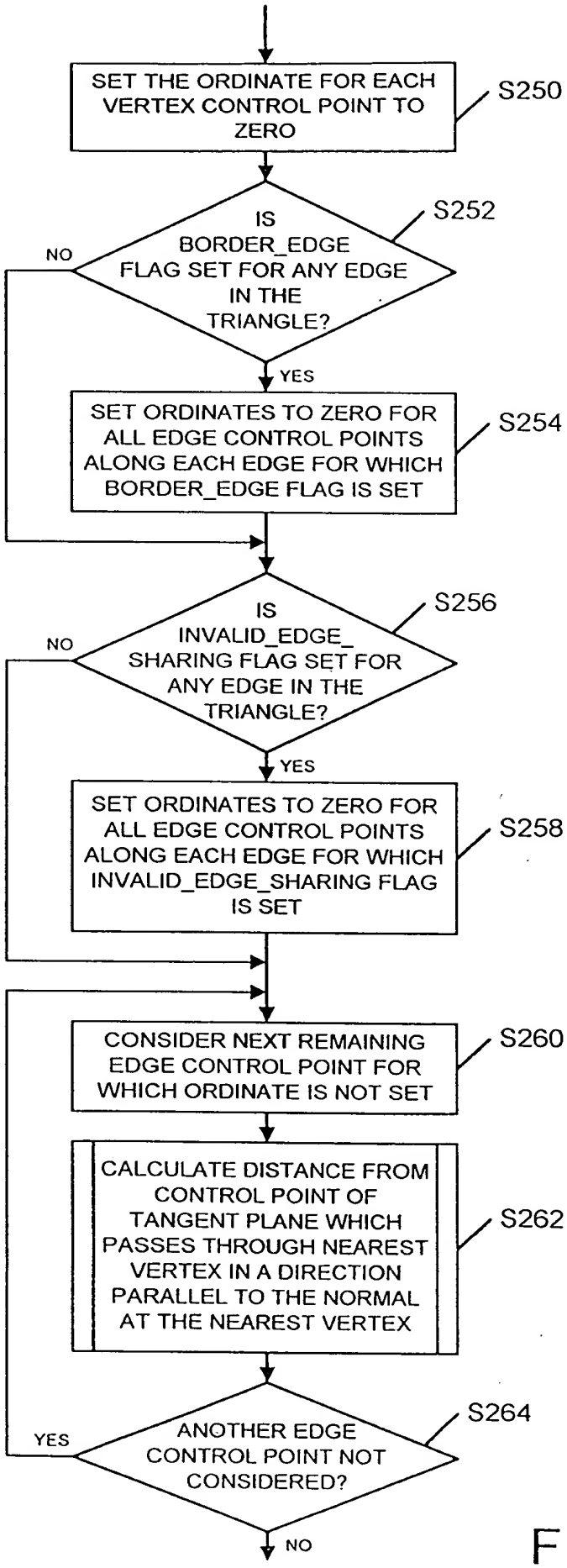
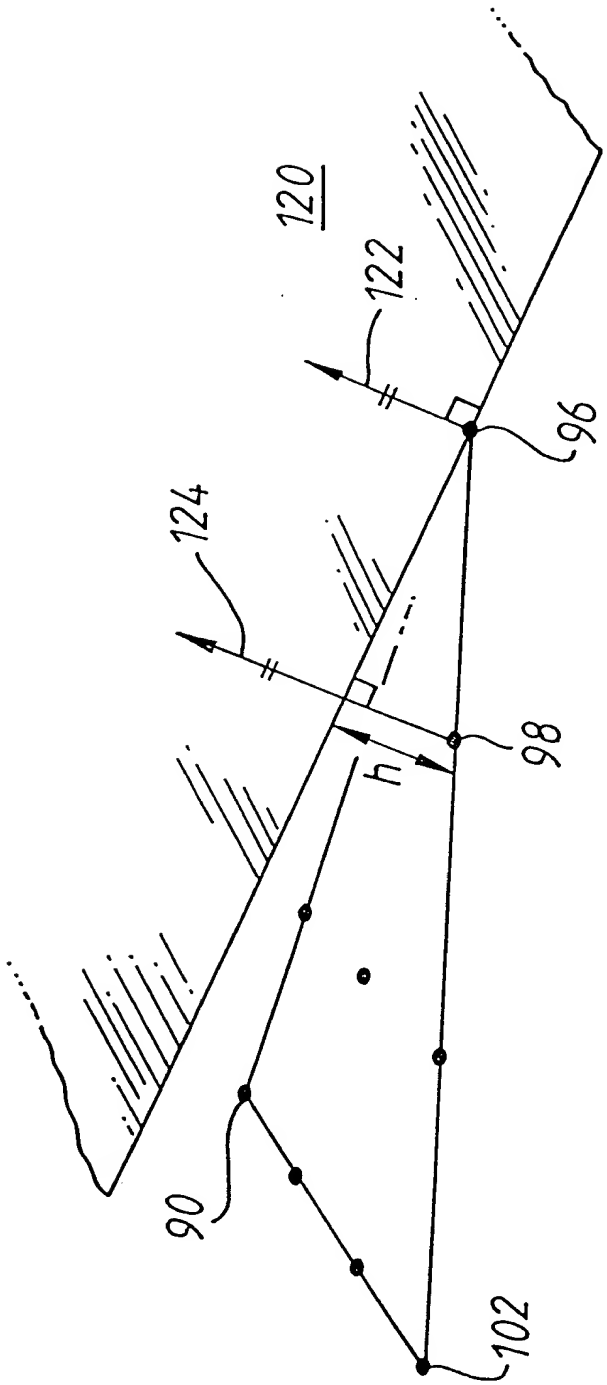

SET THE ORDINATE FOR EACH VERTEX CONTROL POINT TO ZERO
S250
IS BORDER_EDGE FLAG SET FOR ANY EDGE IN THE TRIANGLE?
S252
NO
YES
SET ORDINATES TO ZERO FOR ALL EDGE CONTROL POINTS ALONG EACH EDGE FOR WHICH BORDER_EDGE FLAG IS SET
S254
IS INVALID_EDGE_ SHARING FLAG SET FOR ANY EDGE IN THE TRIANGLE?
S256
NO
YES
SET ORDINATES TO ZERO FOR ALL EDGE CONTROL POINTS ALONG EACH EDGE FOR WHICH INVALID_EDGE_SHARING FLAG IS SET
S258
CONSIDER NEXT REMAINING EDGE CONTROL POINT FOR WHICH ORDINATE IS NOT SET
S260
CALCULATE DISTANCE FROM CONTROL POINT OF TANGENT PLANE WHICH PASSES THROUGH NEAREST VERTEX IN A DIRECTION PARALLEL TO THE NORMAL AT THE NEAREST VERTEX
S262
ANOTHER EDGE CONTROL POINT NOT CONSIDERED?
S264
YES
NO

FIG. 11

FIG. 12



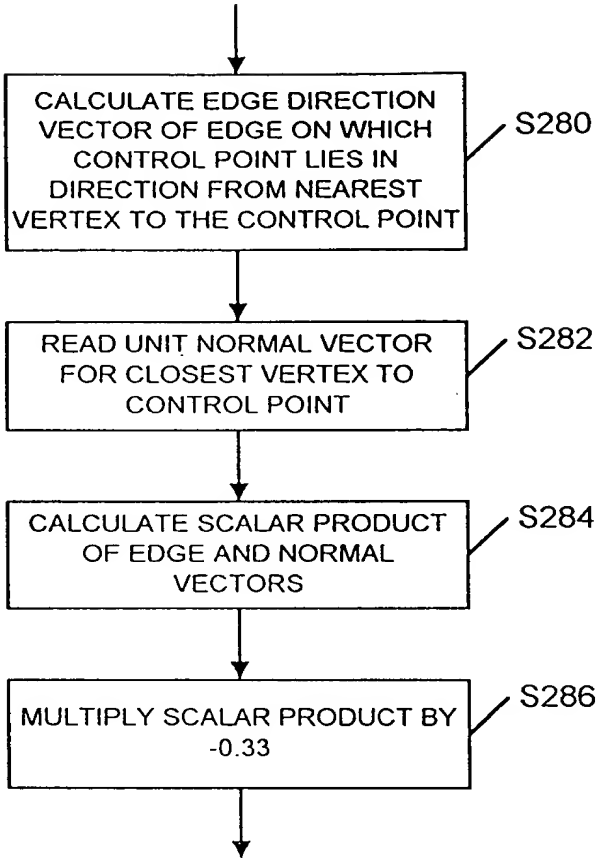

CALCULATE EDGE DIRECTION VECTOR OF EDGE ON WHICH CONTROL POINT LIES IN DIRECTION FROM NEAREST VERTEX TO THE CONTROL POINT
S280
READ UNIT NORMAL VECTOR FOR CLOSEST VERTEX TO CONTROL POINT
S282
CALCULATE SCALAR PRODUCT OF EDGE AND NORMAL VECTORS
S284
MULTIPLY SCALAR PRODUCT BY -0.33
S286

FIG. 13

FIG. 14A

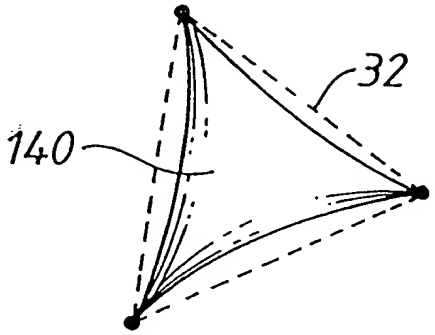


FIG. 14B

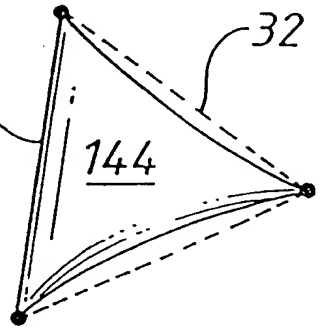


FIG. 14C

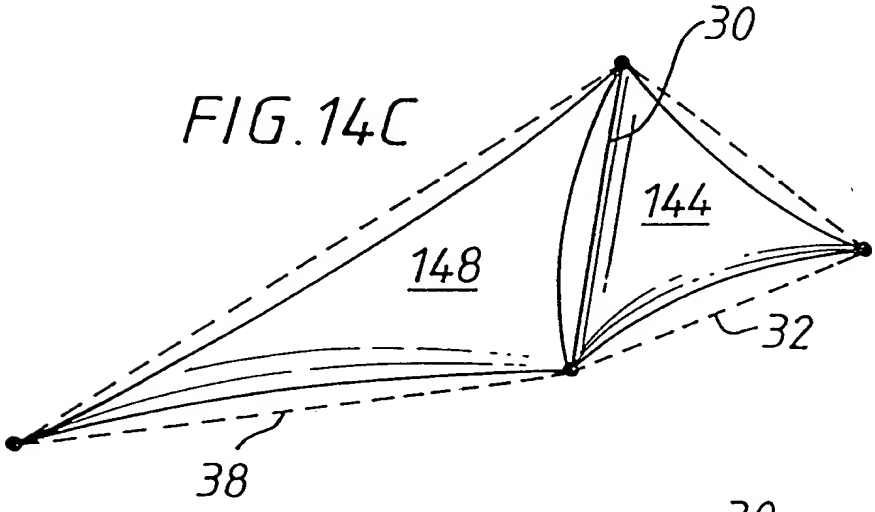
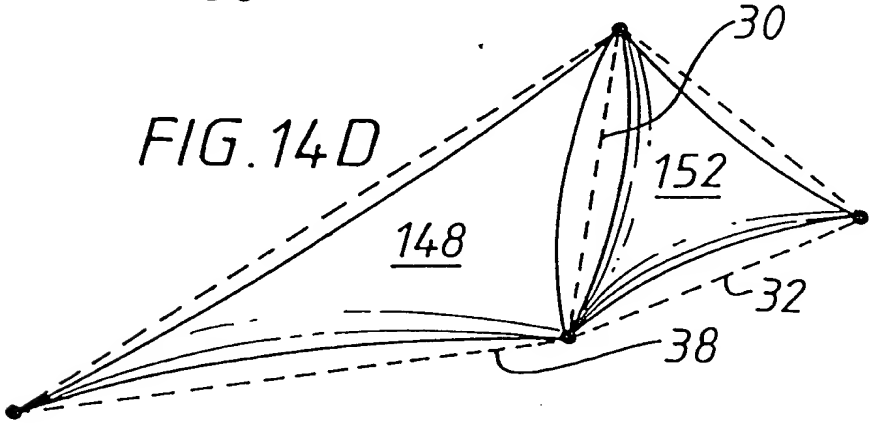


FIG. 14D



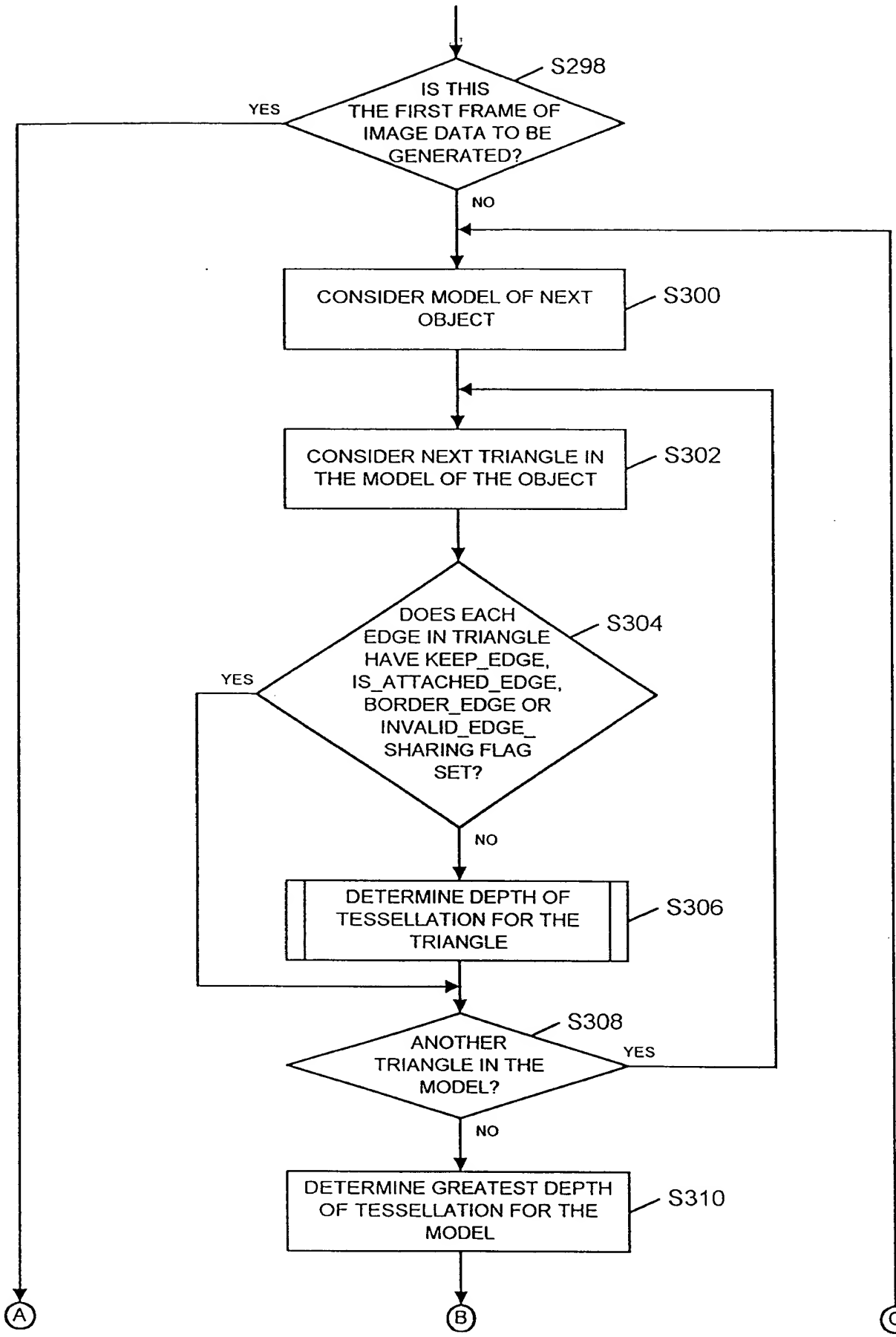

S298
IS THIS THE FIRST FRAME OF IMAGE DATA TO BE GENERATED?
YES
NO
CONSIDER MODEL OF NEXT OBJECT
S300
CONSIDER NEXT TRIANGLE IN THE MODEL OF THE OBJECT
S302
DOES EACH EDGE IN TRIANGLE HAVE KEEP_EDGE, IS_ATTACHED_EDGE, BORDER_EDGE OR INVALID_EDGE_ SHARING FLAG SET?
S304
YES
NO
DETERMINE DEPTH OF TESSELLATION FOR THE TRIANGLE
S306
ANOTHER TRIANGLE IN THE MODEL?
S308
YES
NO
DETERMINE GREATEST DEPTH OF TESSELLATION FOR THE MODEL
S310
A
B
C

FIG. 15

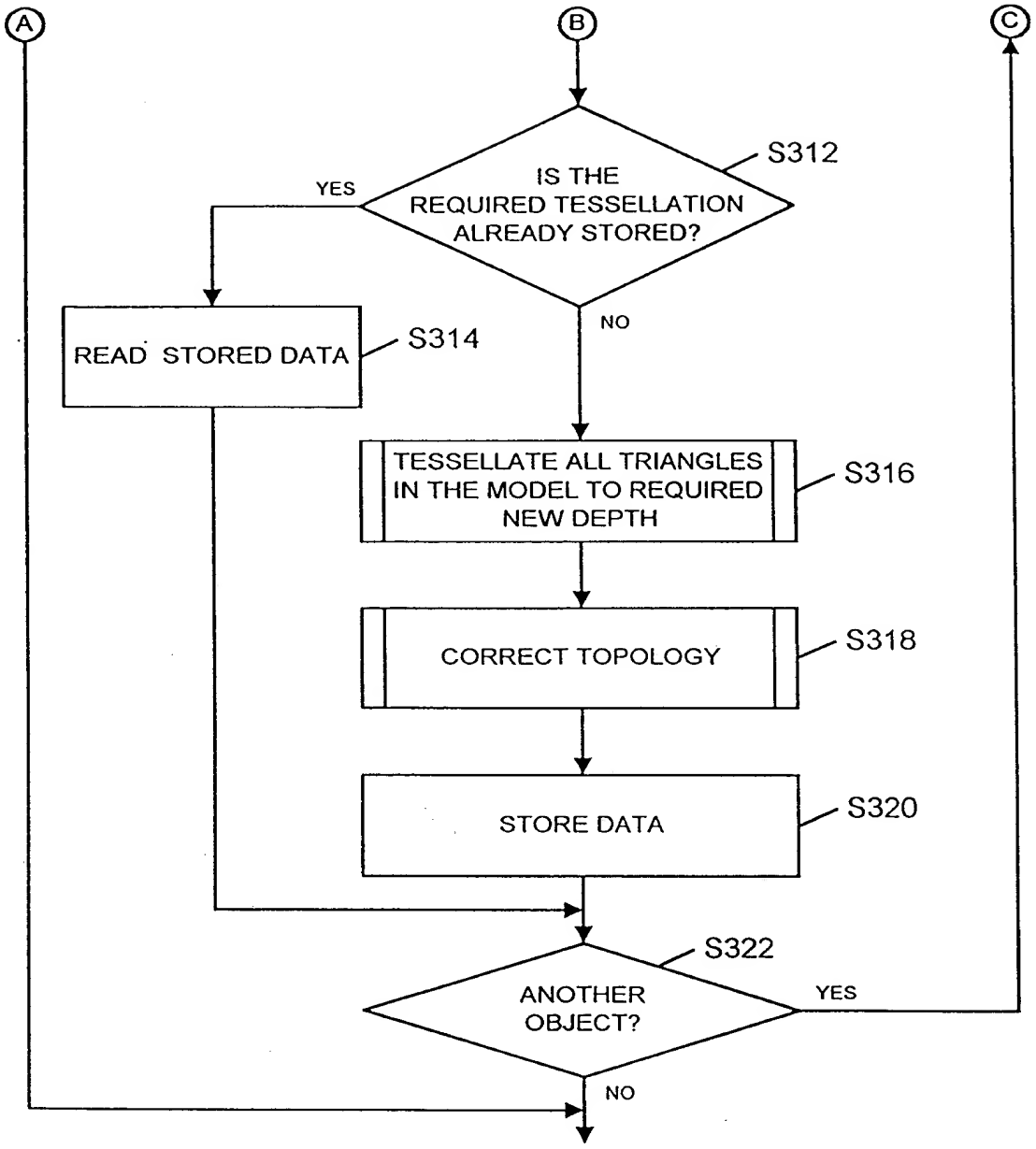

A
B
C
IS THE REQUIRED TESSELLATION ALREADY STORED?
S312
YES
NO
READ STORED DATA
S314
TESSELLATE ALL TRIANGLES IN THE MODEL TO REQUIRED NEW DEPTH
S316
CORRECT TOPOLOGY
S318
STORE DATA
S320
ANOTHER OBJECT?
S322
YES
NO

FIG. 15 (cont)

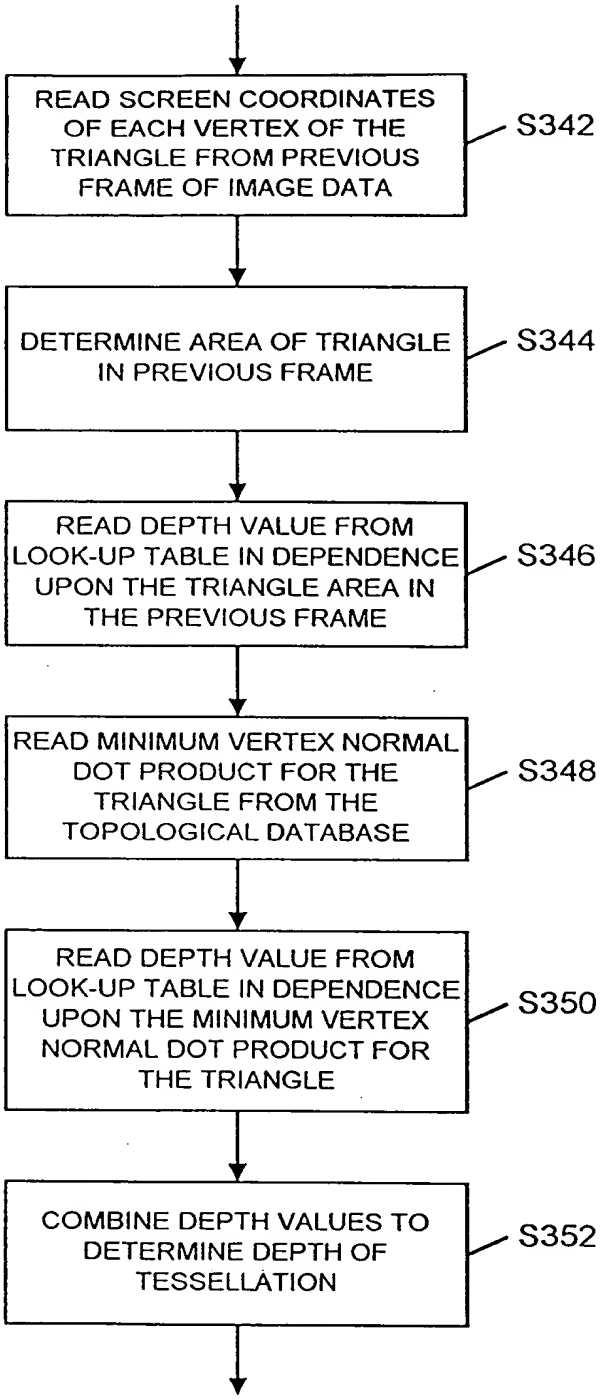

READ SCREEN COORDINATES OF EACH VERTEX OF THE TRIANGLE FROM PREVIOUS FRAME OF IMAGE DATA
S342
DETERMINE AREA OF TRIANGLE IN PREVIOUS FRAME
S344
READ DEPTH VALUE FROM LOOK-UP TABLE IN DEPENDENCE UPON THE TRIANGLE AREA IN THE PREVIOUS FRAME
S346
READ MINIMUM VERTEX NORMAL DOT PRODUCT FOR THE TRIANGLE FROM THE TOPOLOGICAL DATABASE
S348
READ DEPTH VALUE FROM LOOK-UP TABLE IN DEPENDENCE UPON THE MINIMUM VERTEX NORMAL DOT PRODUCT FOR THE TRIANGLE
S350
COMBINE DEPTH VALUES TO DETERMINE DEPTH OF TESSELLATION
S352

FIG. 16

AREA, A, OF TRIANGLE (PIXELS)	DEPTH VALUE
$A < 50$	1
$50 \leq A < 200$	2
$200 \leq A < 450$	3
$450 \leq A < 800$	4
$800 \leq A < 1250$	5
$1250 \leq A < 1800$	6
$1800 \leq A < 2450$	7
$2450 \leq A < 3200$	8
$3200 \leq A < 4050$	9
$A \geq 4050$	10

FIG. 17A

MINIMUM VERTEX NORMAL DOT PRODUCT, DP_{min}	DEPTH VALUE
$DP_{min} > 0.95$	1
$0.75 < DP_{min} \leq 0.95$	2
$0.50 < DP_{min} \leq 0.75$	3
$0.25 < DP_{min} \leq 0.50$	4
$0.00 < DP_{min} \leq 0.25$	5
$-0.25 < DP_{min} \leq 0.00$	6
$-0.50 < DP_{min} \leq -0.25$	7
$-0.75 < DP_{min} \leq -0.50$	8
$-0.95 < DP_{min} \leq -0.75$	9
$DP_{min} < -0.95$	10

FIG. 17B

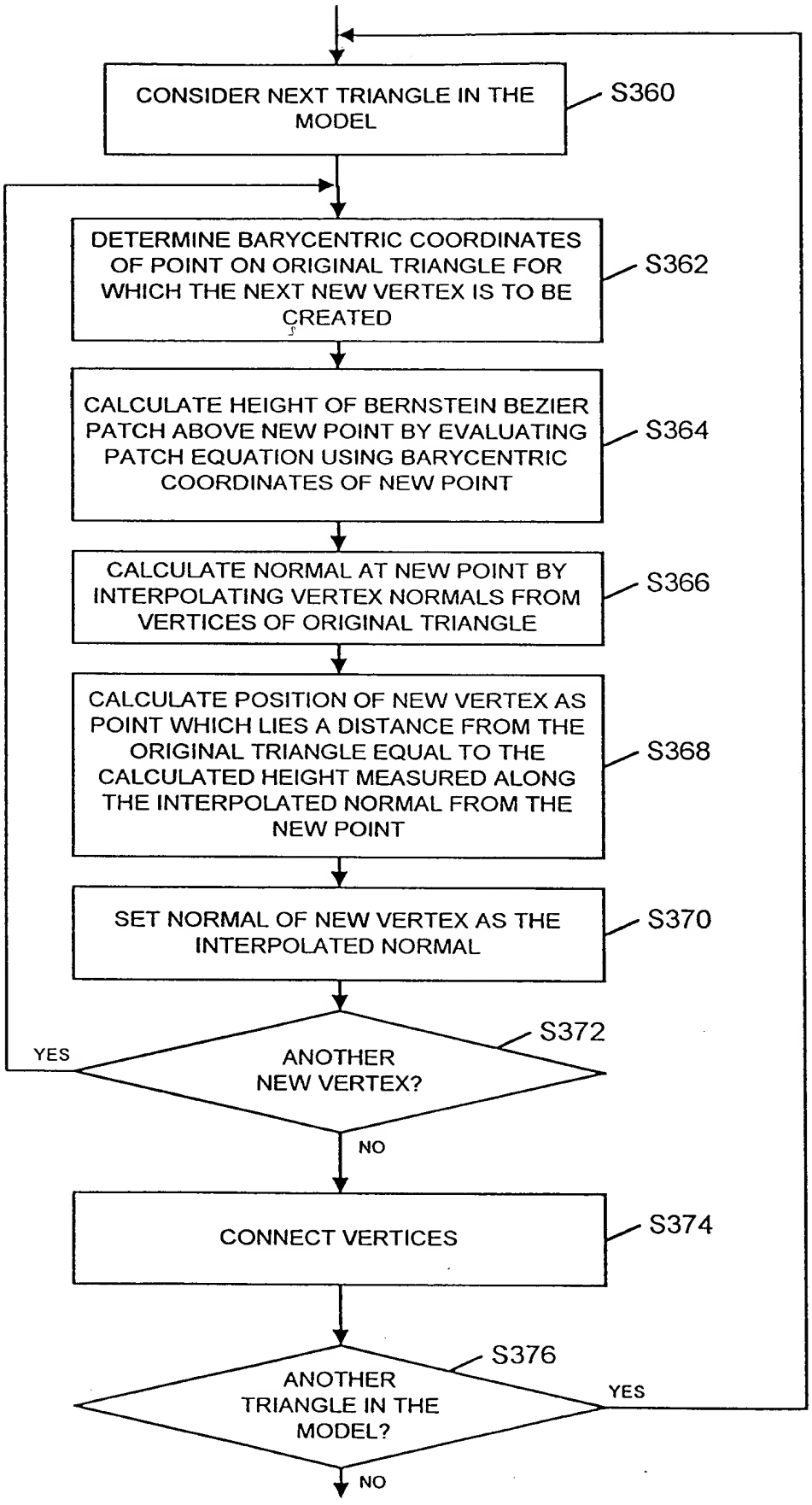

CONSIDER NEXT TRIANGLE IN THE MODEL
S360
DETERMINE BARYCENTRIC COORDINATES OF POINT ON ORIGINAL TRIANGLE FOR WHICH THE NEXT NEW VERTEX IS TO BE CREATED
S362
CALCULATE HEIGHT OF BERNSTEIN BEZIER PATCH ABOVE NEW POINT BY EVALUATING PATCH EQUATION USING BARYCENTRIC COORDINATES OF NEW POINT
S364
CALCULATE NORMAL AT NEW POINT BY INTERPOLATING VERTEX NORMALS FROM VERTICES OF ORIGINAL TRIANGLE
S366
CALCULATE POSITION OF NEW VERTEX AS POINT WHICH LIES A DISTANCE FROM THE ORIGINAL TRIANGLE EQUAL TO THE CALCULATED HEIGHT MEASURED ALONG THE INTERPOLATED NORMAL FROM THE NEW POINT
S368
SET NORMAL OF NEW VERTEX AS THE INTERPOLATED NORMAL
S370
ANOTHER NEW VERTEX?
S372
YES
NO
CONNECT VERTICES
S374
ANOTHER TRIANGLE IN THE MODEL?
S376
YES
NO

FIG. 18

FIG. 19A

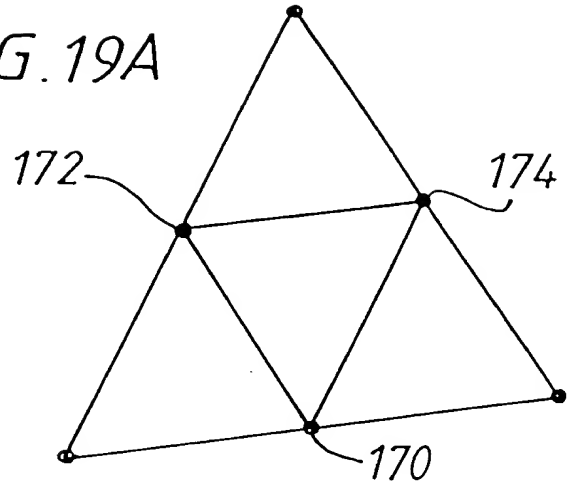


FIG. 19B

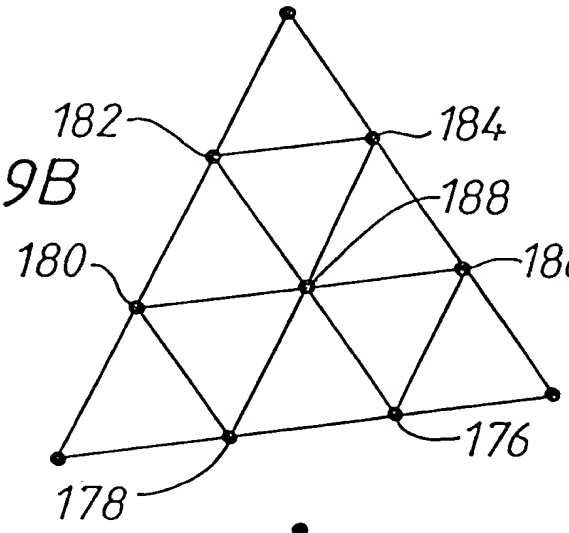


FIG. 19C

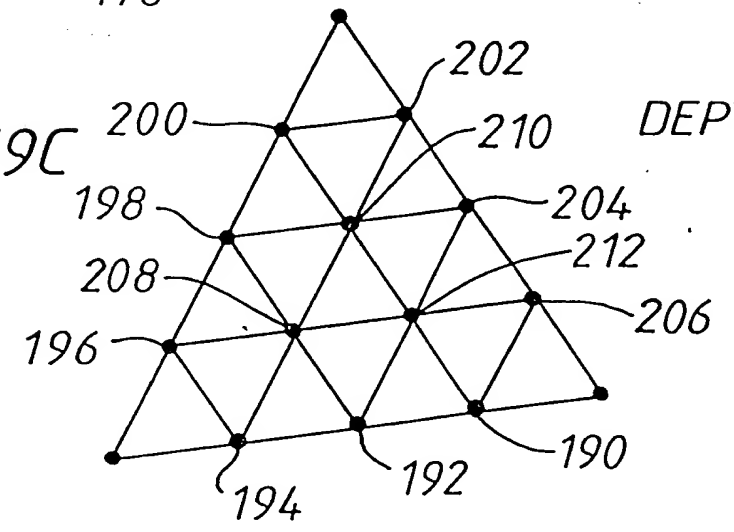


FIG. 20

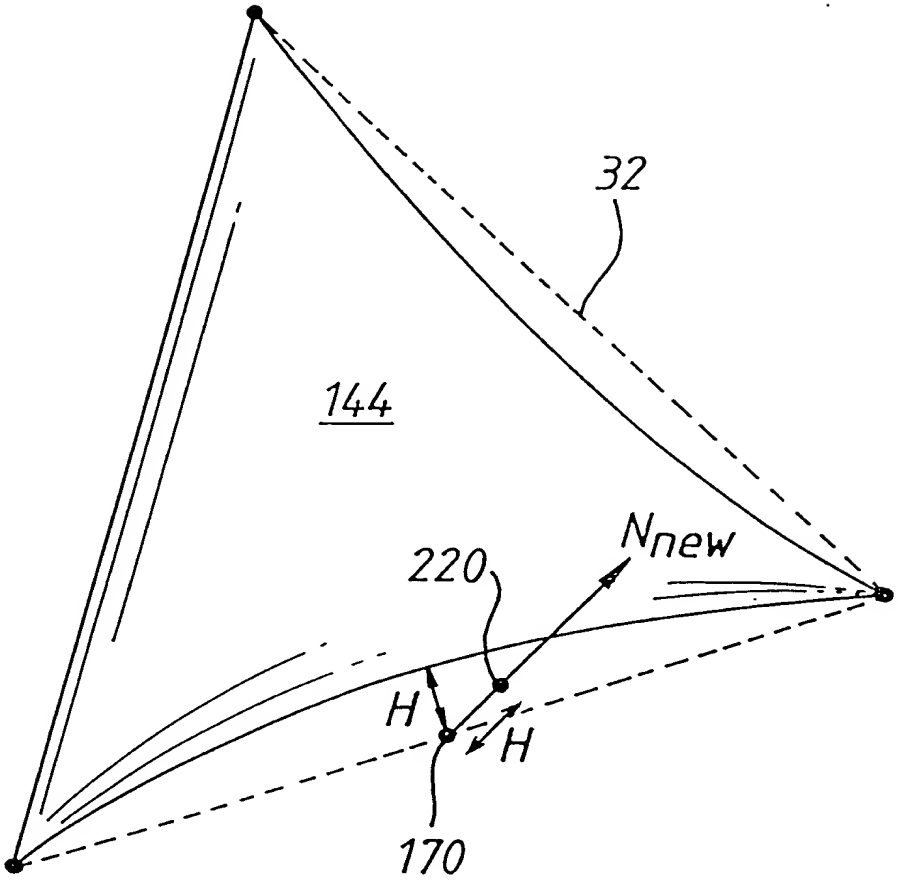


FIG. 21A

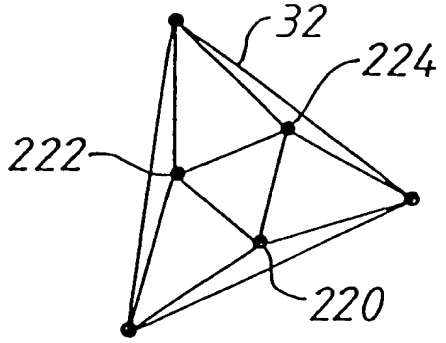


FIG. 21B

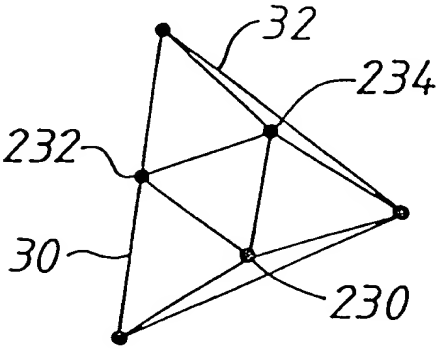


FIG. 21C

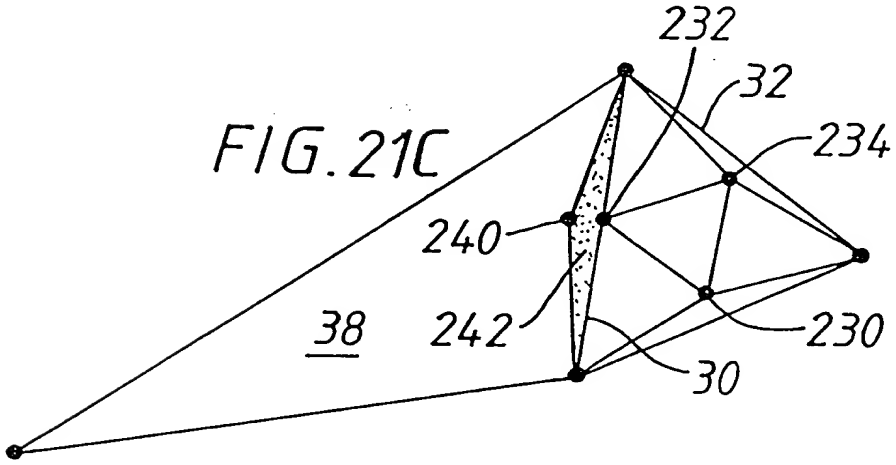
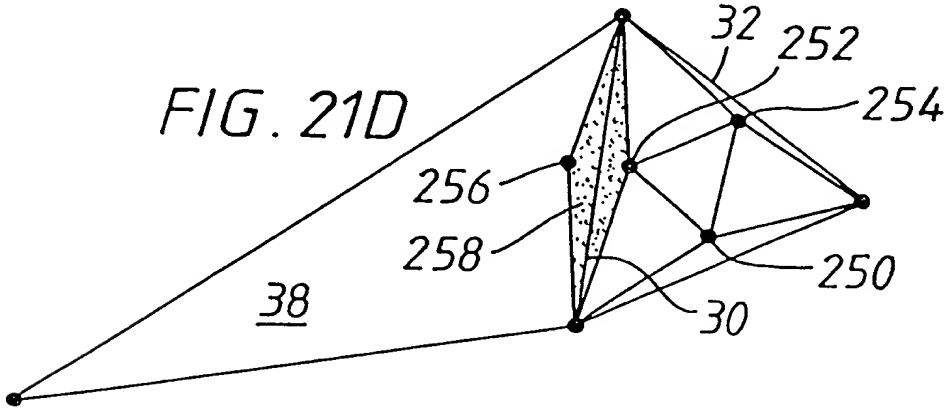


FIG. 21D



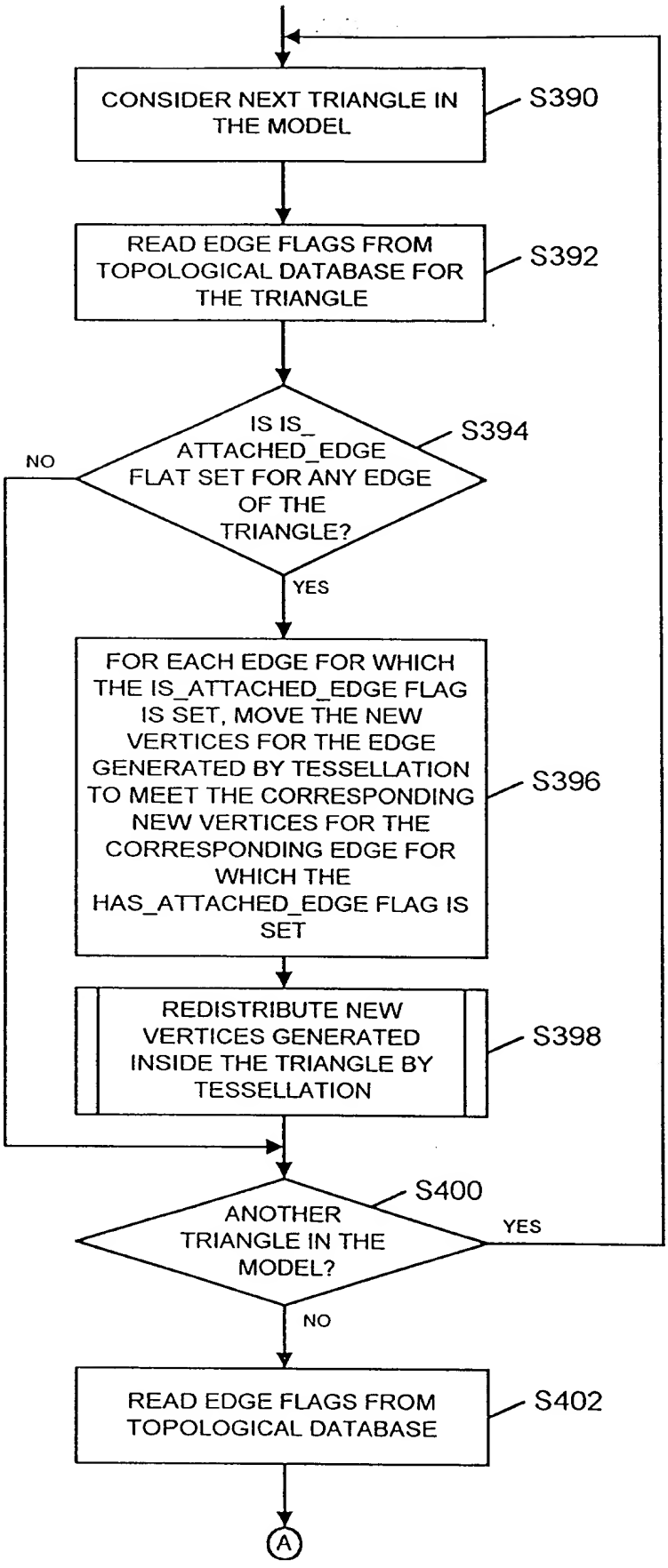

CONSIDER NEXT TRIANGLE IN THE MODEL
S390
READ EDGE FLAGS FROM TOPOLOGICAL DATABASE FOR THE TRIANGLE
S392
IS IS_ ATTACHED_EDGE FLAT SET FOR ANY EDGE OF THE TRIANGLE?
S394
NO
YES
FOR EACH EDGE FOR WHICH THE IS_ATTACHED_EDGE FLAG IS SET, MOVE THE NEW VERTICES FOR THE EDGE GENERATED BY TESSELLATION TO MEET THE CORRESPONDING NEW VERTICES FOR THE CORRESPONDING EDGE FOR WHICH THE HAS_ATTACHED_EDGE FLAG IS SET
S396
REDISTRIBUTE NEW VERTICES GENERATED INSIDE THE TRIANGLE BY TESSELLATION
S398
ANOTHER TRIANGLE IN THE MODEL?
S400
YES
NO
READ EDGE FLAGS FROM TOPOLOGICAL DATABASE
S402
A

FIG. 22

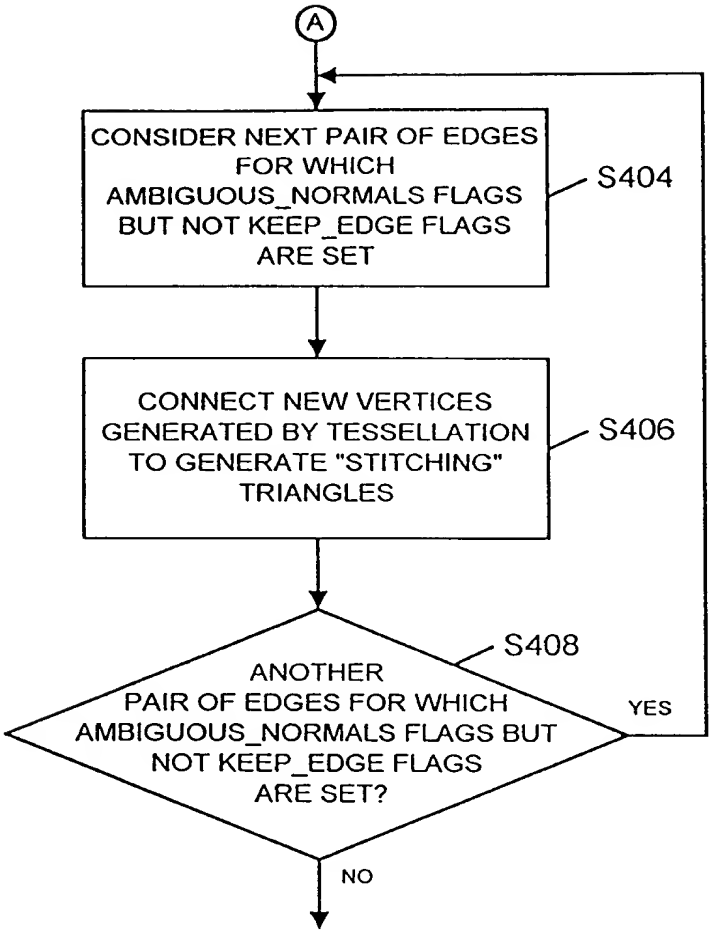

A
CONSIDER NEXT PAIR OF EDGES FOR WHICH AMBIGUOUS_NORMALS FLAGS BUT NOT KEEP_EDGE FLAGS ARE SET
S404
CONNECT NEW VERTICES GENERATED BY TESSELLATION TO GENERATE "STITCHING" TRIANGLES
S406
ANOTHER PAIR OF EDGES FOR WHICH AMBIGUOUS_NORMALS FLAGS BUT NOT KEEP_EDGE FLAGS ARE SET?
S408
YES
NO

FIG. 22 (cont)

FIG. 23A

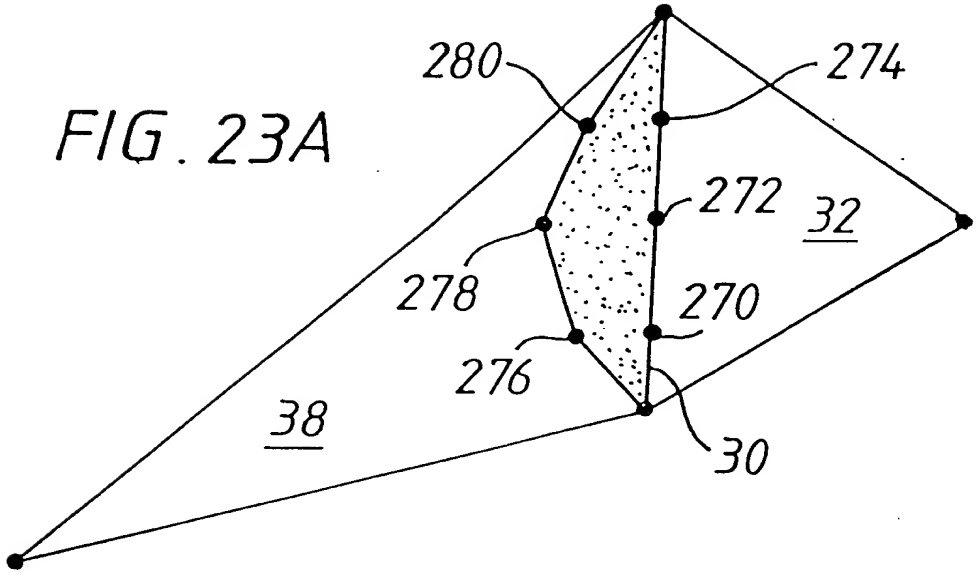
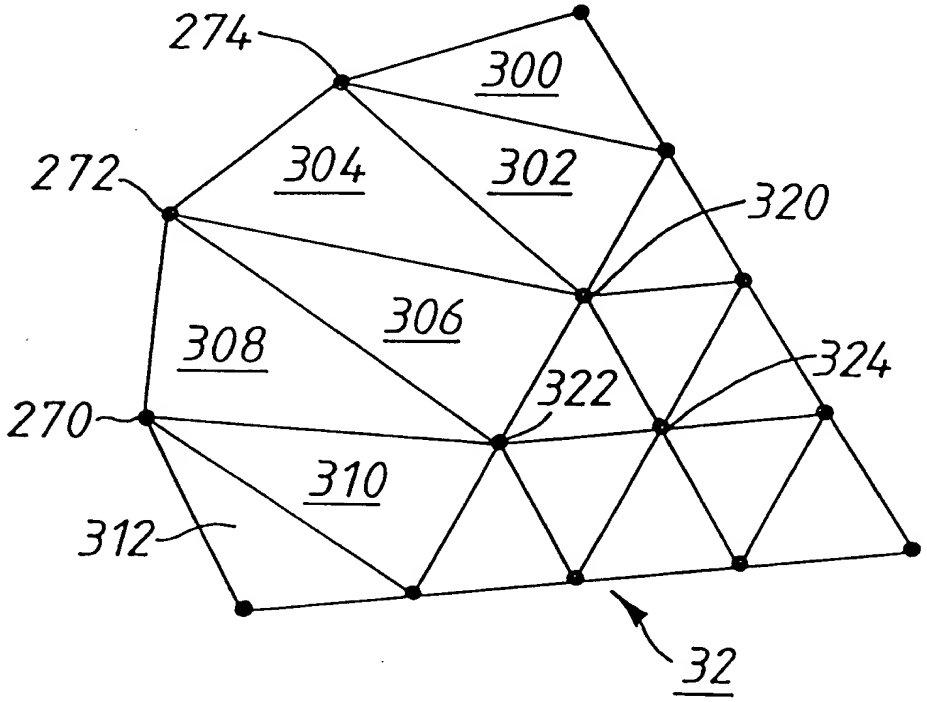


FIG. 23B



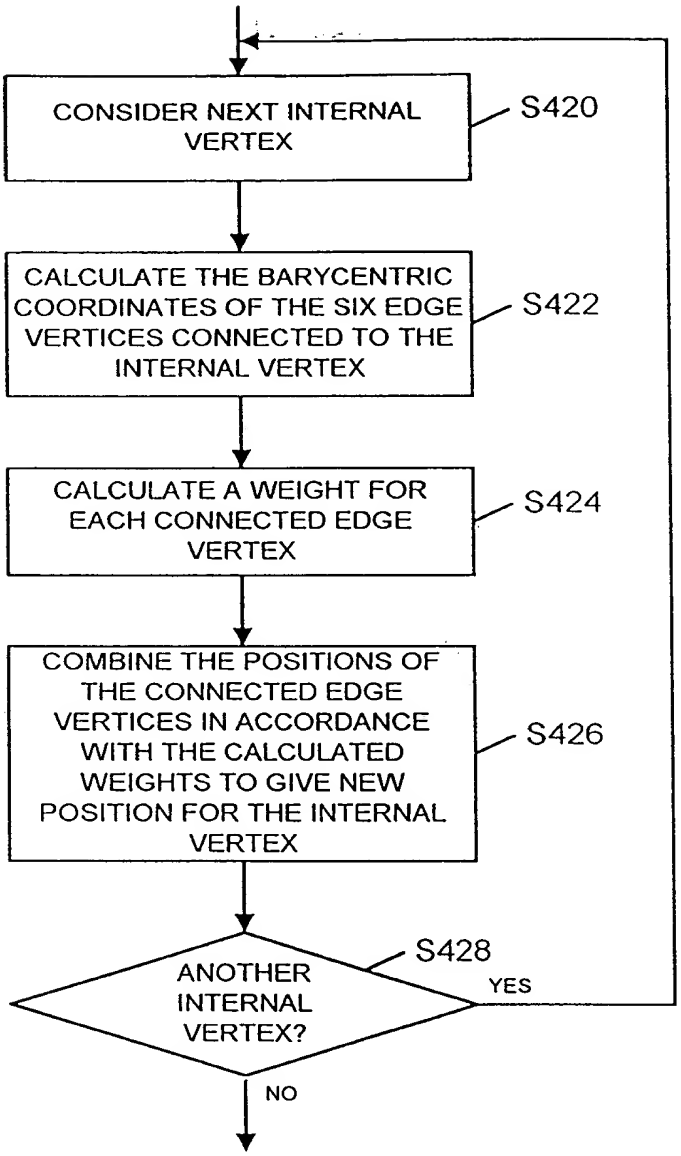

CONSIDER NEXT INTERNAL VERTEX
S420
CALCULATE THE BARYCENTRIC COORDINATES OF THE SIX EDGE VERTICES CONNECTED TO THE INTERNAL VERTEX
S422
CALCULATE A WEIGHT FOR EACH CONNECTED EDGE VERTEX
S424
COMBINE THE POSITIONS OF THE CONNECTED EDGE VERTICES IN ACCORDANCE WITH THE CALCULATED WEIGHTS TO GIVE NEW POSITION FOR THE INTERNAL VERTEX
S426
ANOTHER INTERNAL VERTEX?
S428
YES
NO

FIG. 24

FIG. 25

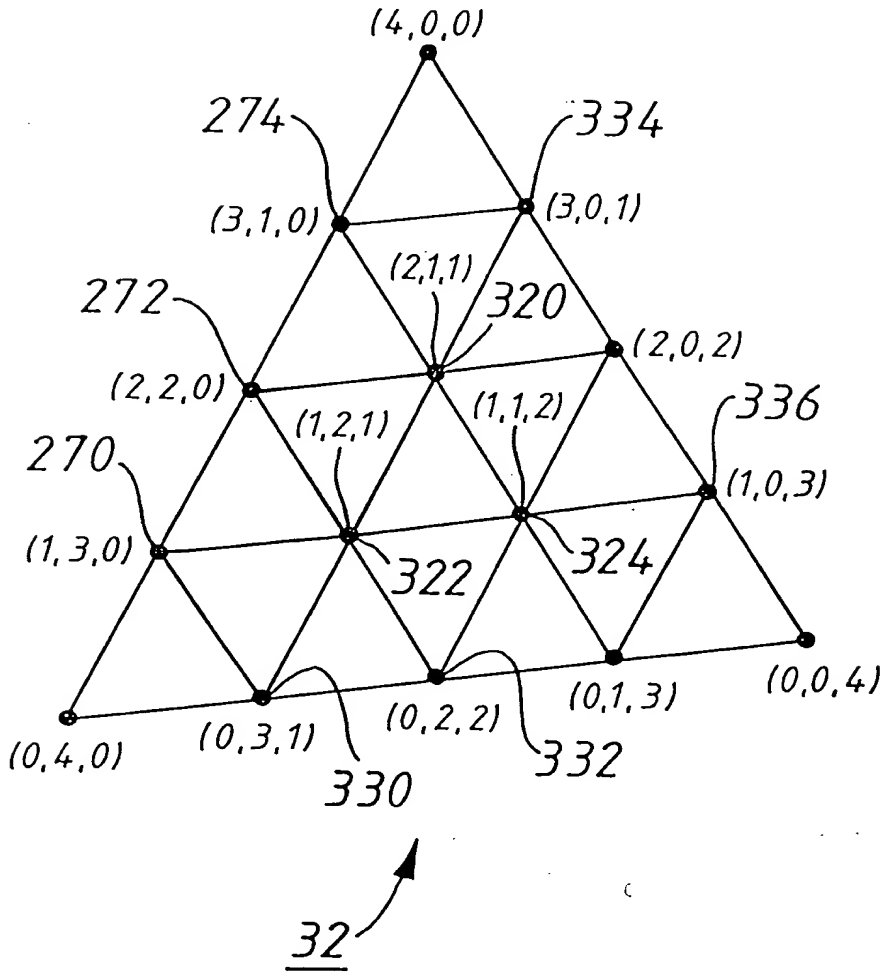

(4,0,0)
274
334
(3,1,0)
(3,0,1)
(2,1,1)
272
320
(2,0,2)
(2,2,0)
(1,2,1)
(1,1,2)
336
270
(1,0,3)
(1,3,0)
322
324
(0,0,4)
(0,1,3)
(0,2,2)
(0,3,1)
(0,4,0)
330
332
32

FIG. 26A

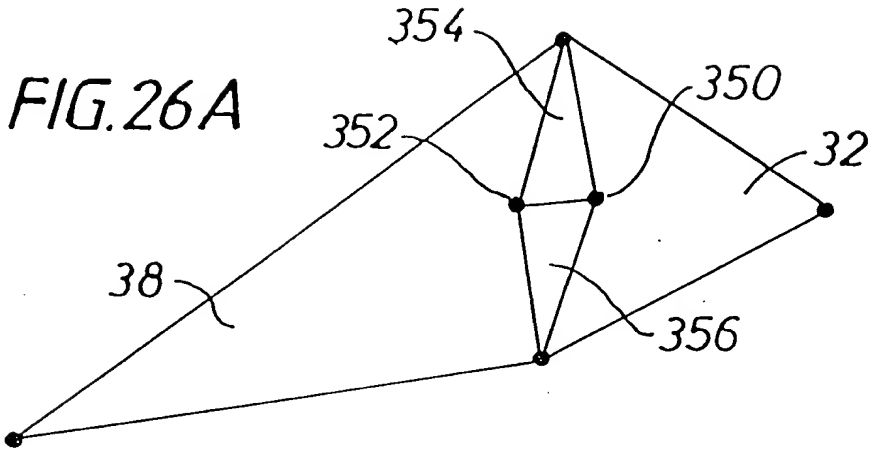


FIG. 26B

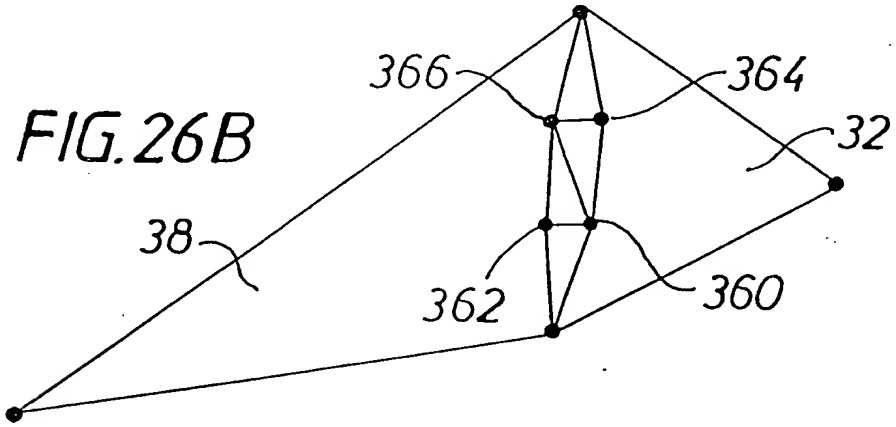
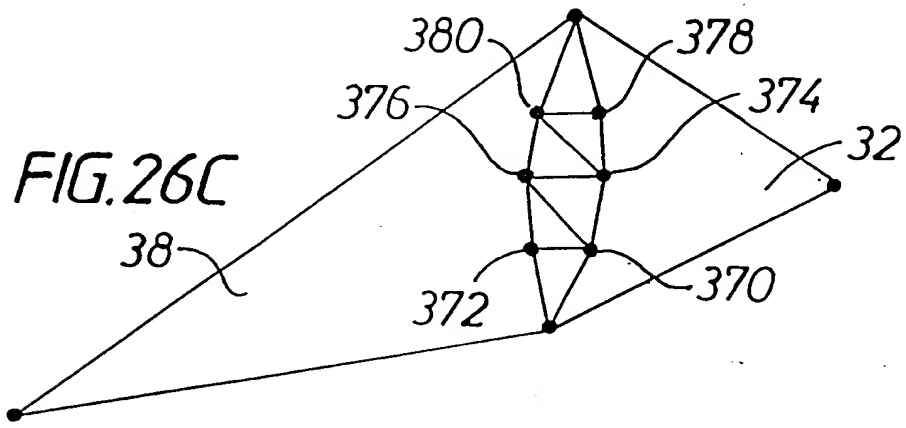


FIG. 26C



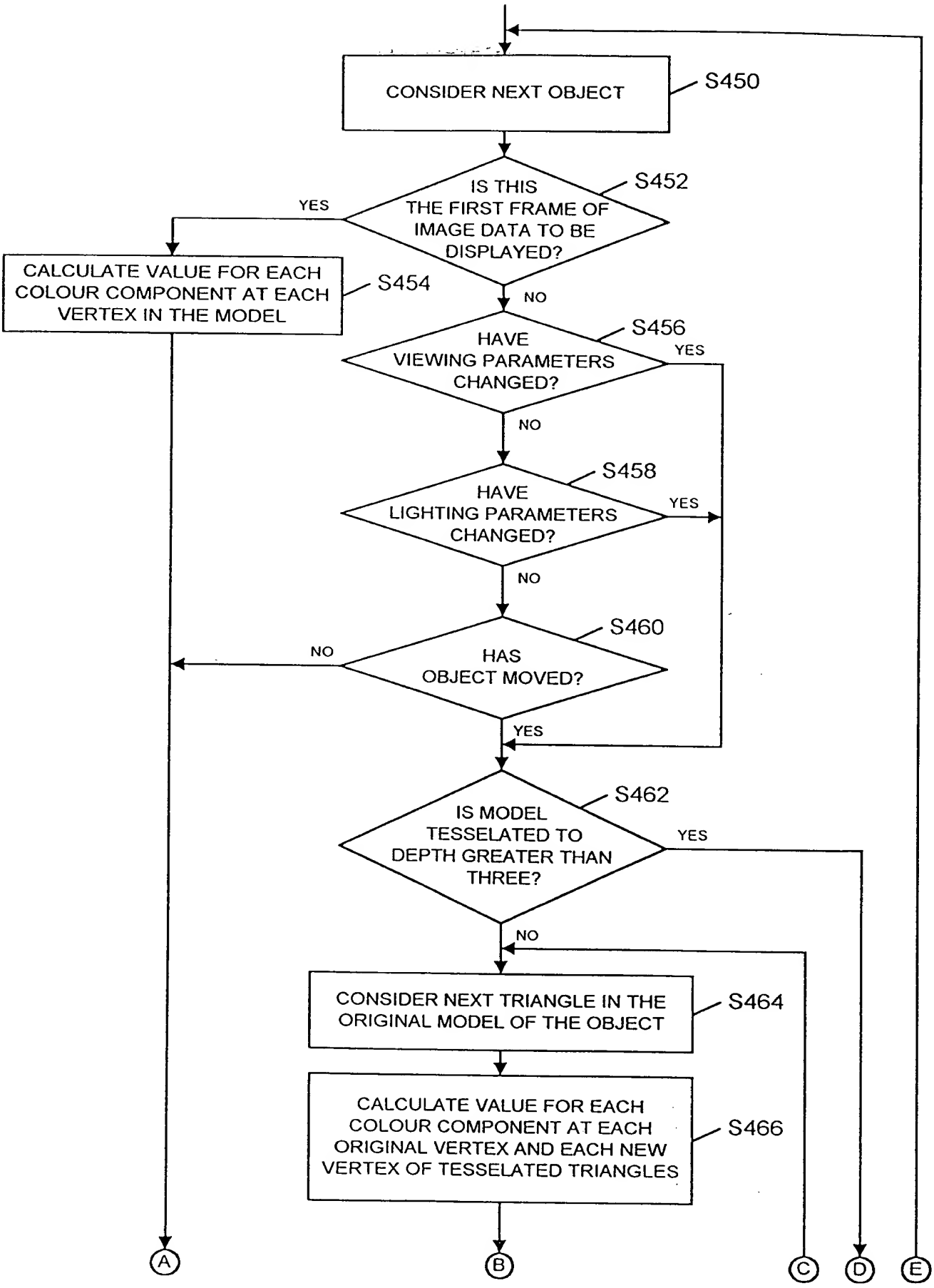

CONSIDER NEXT OBJECT
S450
IS THIS THE FIRST FRAME OF IMAGE DATA TO BE DISPLAYED?
S452
YES
NO
CALCULATE VALUE FOR EACH COLOUR COMPONENT AT EACH VERTEX IN THE MODEL
S454
HAVE VIEWING PARAMETERS CHANGED?
S456
YES
NO
HAVE LIGHTING PARAMETERS CHANGED?
S458
YES
NO
HAS OBJECT MOVED?
S460
NO
YES
IS MODEL TESSELATED TO DEPTH GREATER THAN THREE?
S462
YES
NO
CONSIDER NEXT TRIANGLE IN THE ORIGINAL MODEL OF THE OBJECT
S464
CALCULATE VALUE FOR EACH COLOUR COMPONENT AT EACH ORIGINAL VERTEX AND EACH NEW VERTEX OF TESSELATED TRIANGLES
S466
A
B
C
D
E

FIG. 27

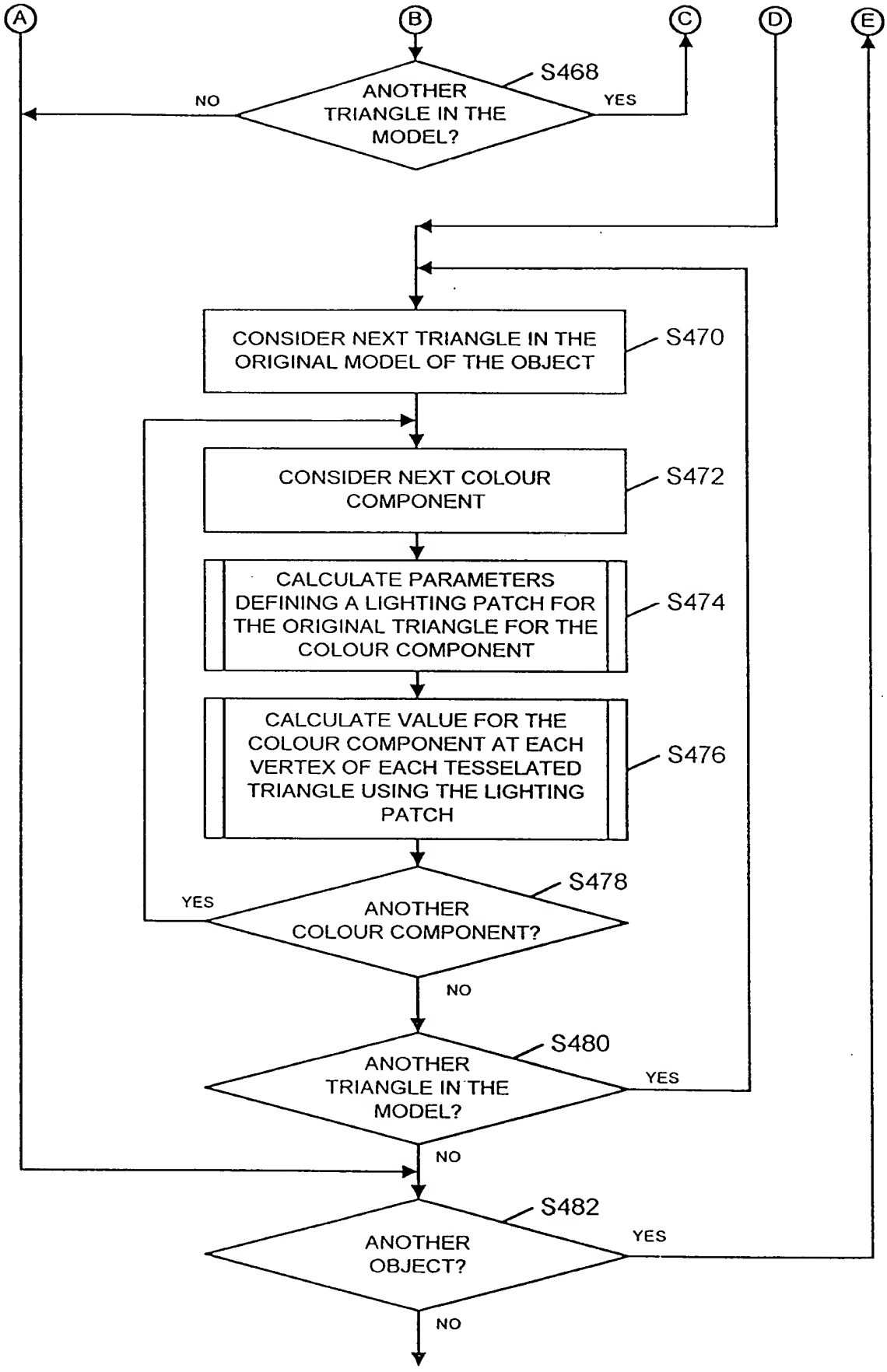

A
B
C
D
E
S468
ANOTHER TRIANGLE IN THE MODEL?
NO
YES
CONSIDER NEXT TRIANGLE IN THE ORIGINAL MODEL OF THE OBJECT
S470
CONSIDER NEXT COLOUR COMPONENT
S472
CALCULATE PARAMETERS DEFINING A LIGHTING PATCH FOR THE ORIGINAL TRIANGLE FOR THE COLOUR COMPONENT
S474
CALCULATE VALUE FOR THE COLOUR COMPONENT AT EACH VERTEX OF EACH TESSELATED TRIANGLE USING THE LIGHTING PATCH
S476
S478
ANOTHER COLOUR COMPONENT?
YES
NO
S480
ANOTHER TRIANGLE IN THE MODEL?
YES
NO
S482
ANOTHER OBJECT?
YES
NO

FIG. 27 (cont)

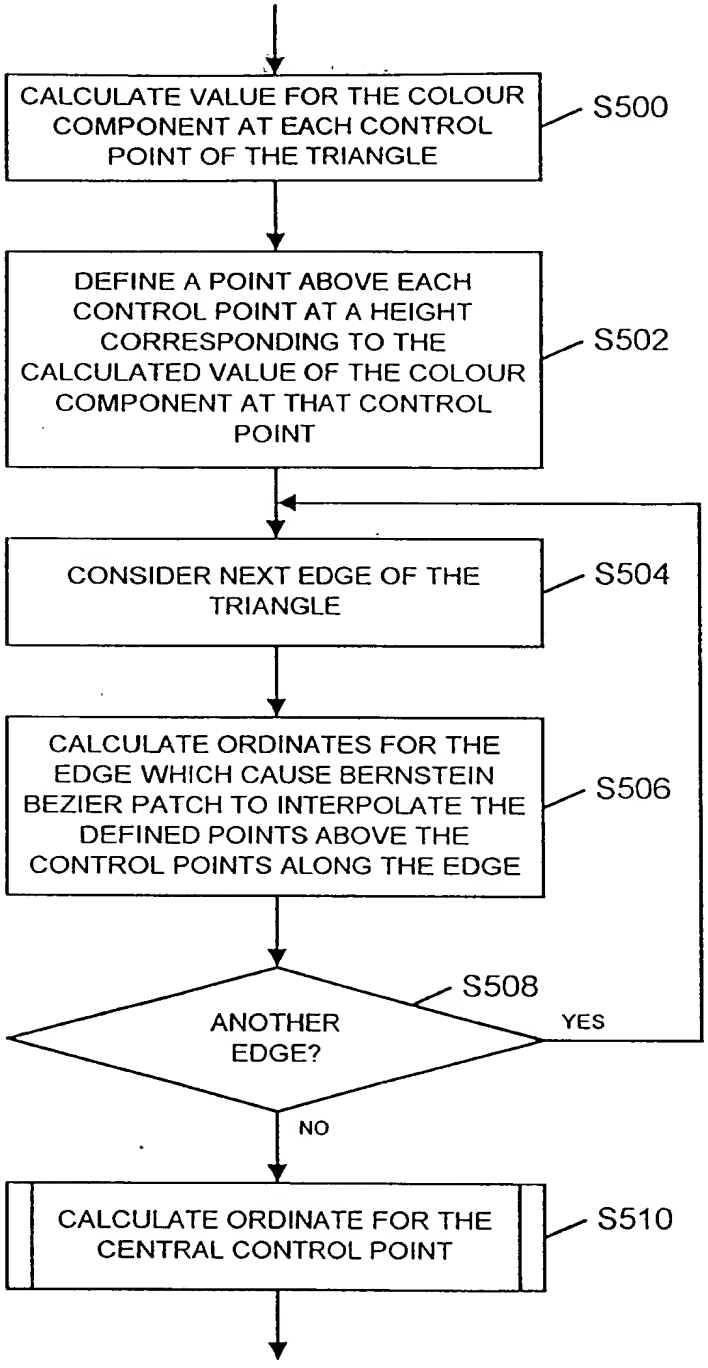

CALCULATE VALUE FOR THE COLOUR COMPONENT AT EACH CONTROL POINT OF THE TRIANGLE
S500
DEFINE A POINT ABOVE EACH CONTROL POINT AT A HEIGHT CORRESPONDING TO THE CALCULATED VALUE OF THE COLOUR COMPONENT AT THAT CONTROL POINT
S502
CONSIDER NEXT EDGE OF THE TRIANGLE
S504
CALCULATE ORDINATES FOR THE EDGE WHICH CAUSE BERNSTEIN BEZIER PATCH TO INTERPOLATE THE DEFINED POINTS ABOVE THE CONTROL POINTS ALONG THE EDGE
S506
ANOTHER EDGE?
S508
YES
NO
CALCULATE ORDINATE FOR THE CENTRAL CONTROL POINT
S510

FIG. 28

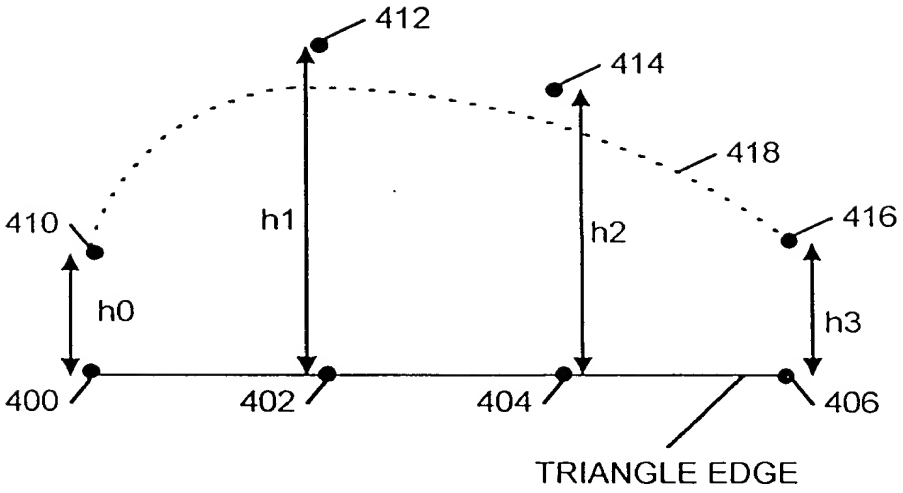


FIG. 29A

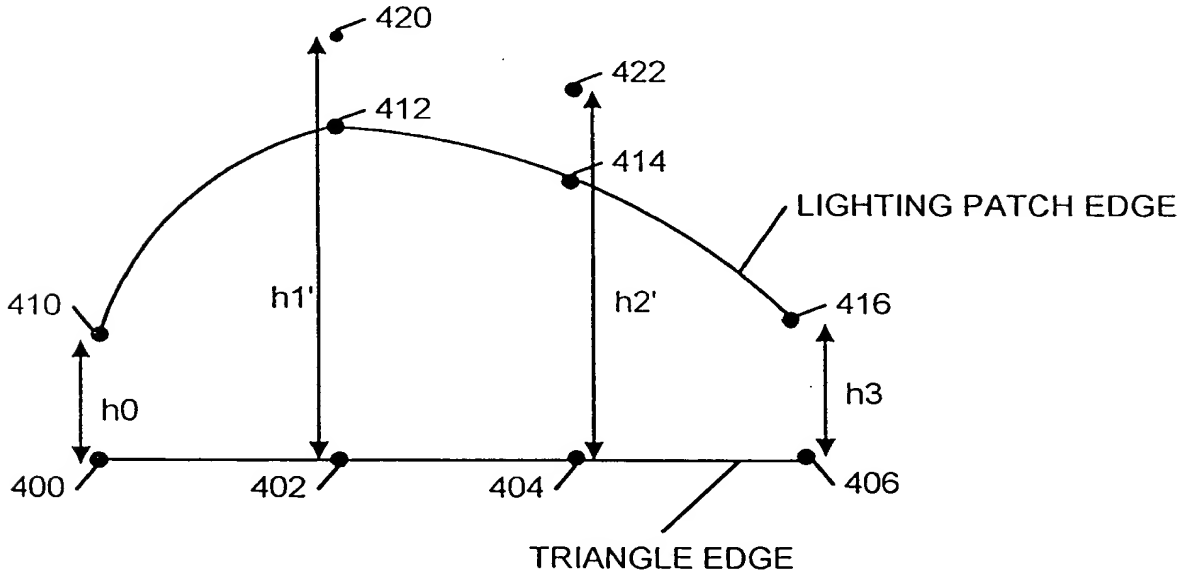


FIG. 29B

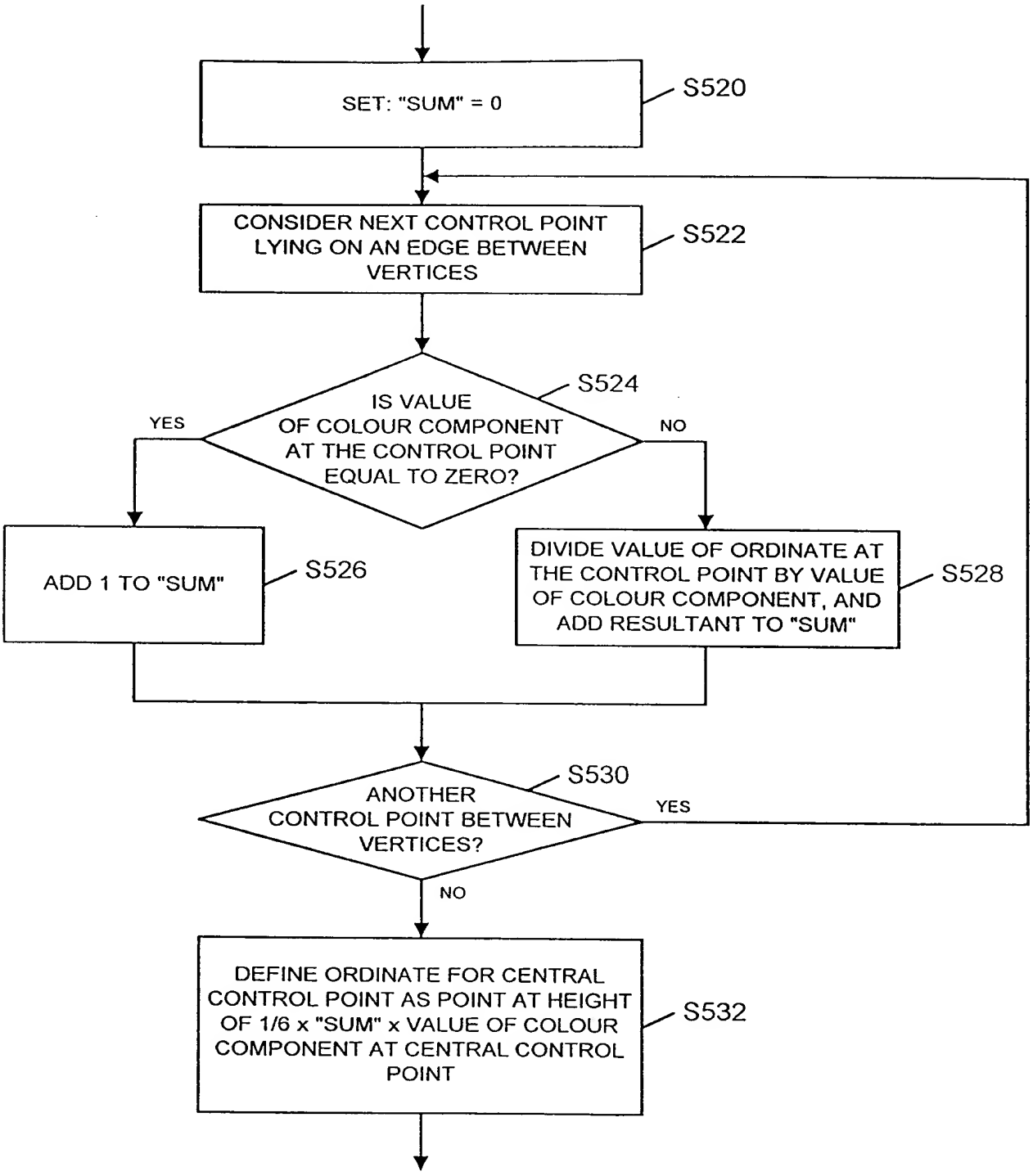

SET: "SUM" = 0
S520
CONSIDER NEXT CONTROL POINT LYING ON AN EDGE BETWEEN VERTICES
S522
IS VALUE OF COLOUR COMPONENT AT THE CONTROL POINT EQUAL TO ZERO?
S524
YES
NO
ADD 1 TO "SUM"
S526
DIVIDE VALUE OF ORDINATE AT THE CONTROL POINT BY VALUE OF COLOUR COMPONENT, AND ADD RESULTANT TO "SUM"
S528
ANOTHER CONTROL POINT BETWEEN VERTICES?
S530
YES
NO
DEFINE ORDINATE FOR CENTRAL CONTROL POINT AS POINT AT HEIGHT OF 1/6 x "SUM" x VALUE OF COLOUR COMPONENT AT CENTRAL CONTROL POINT
S532

FIG. 30

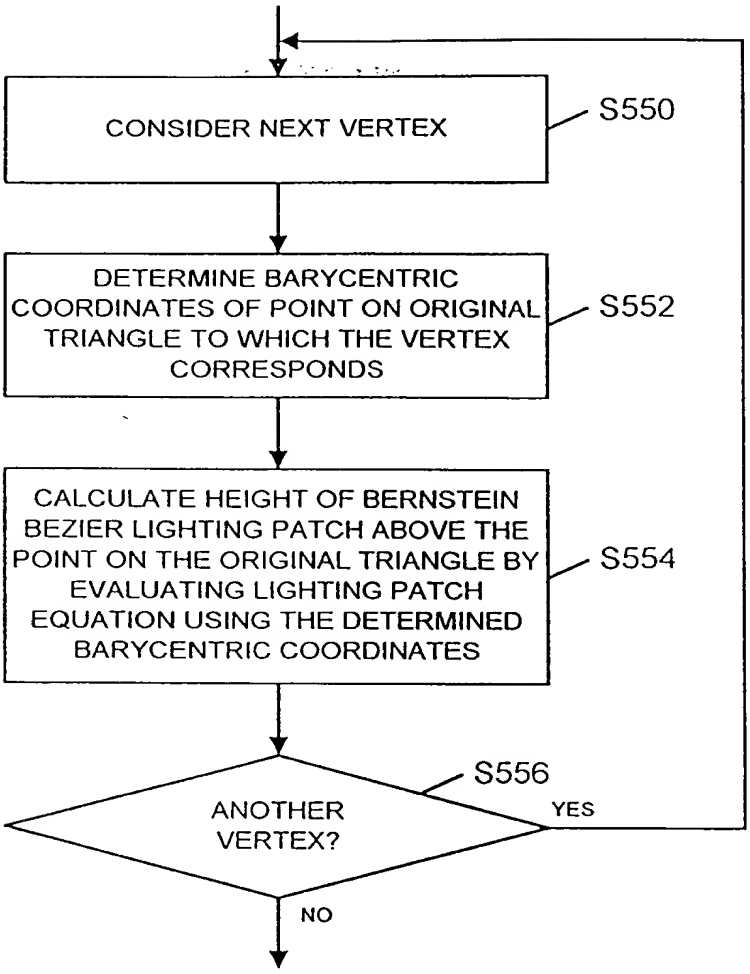

CONSIDER NEXT VERTEX
S550
DETERMINE BARYCENTRIC COORDINATES OF POINT ON ORIGINAL TRIANGLE TO WHICH THE VERTEX CORRESPONDS
S552
CALCULATE HEIGHT OF BERNSTEIN BEZIER LIGHTING PATCH ABOVE THE POINT ON THE ORIGINAL TRIANGLE BY EVALUATING LIGHTING PATCH EQUATION USING THE DETERMINED BARYCENTRIC COORDINATES
S554
ANOTHER VERTEX?
S556
YES
NO

FIG. 31

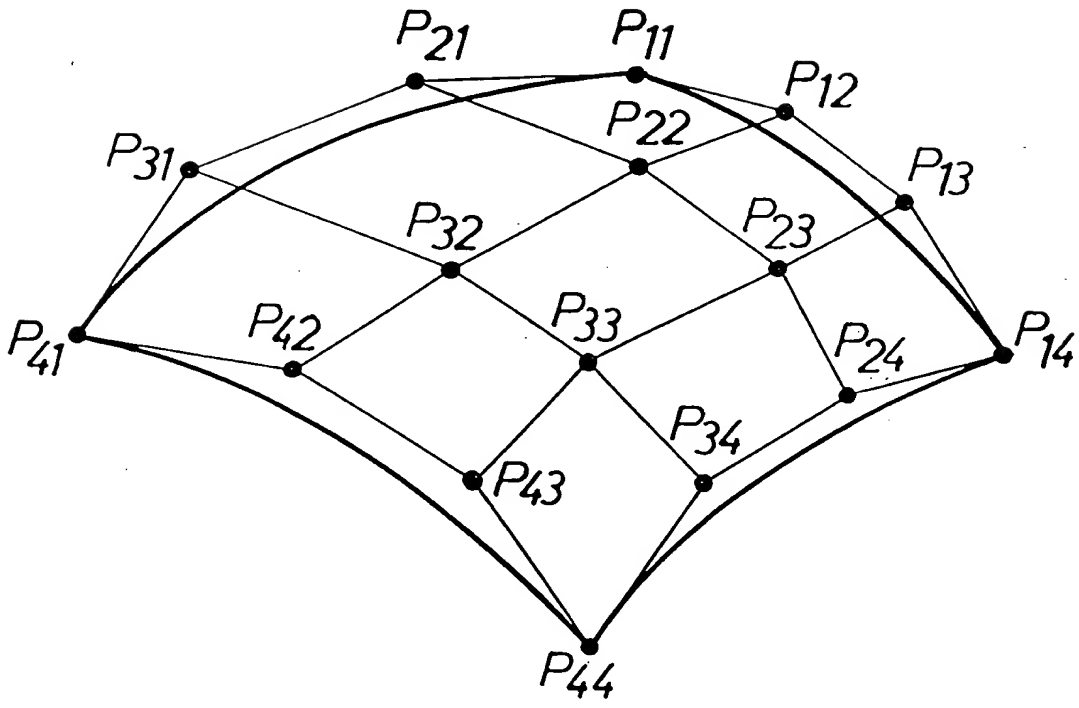



FIG. 32